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GEOPHYSICS

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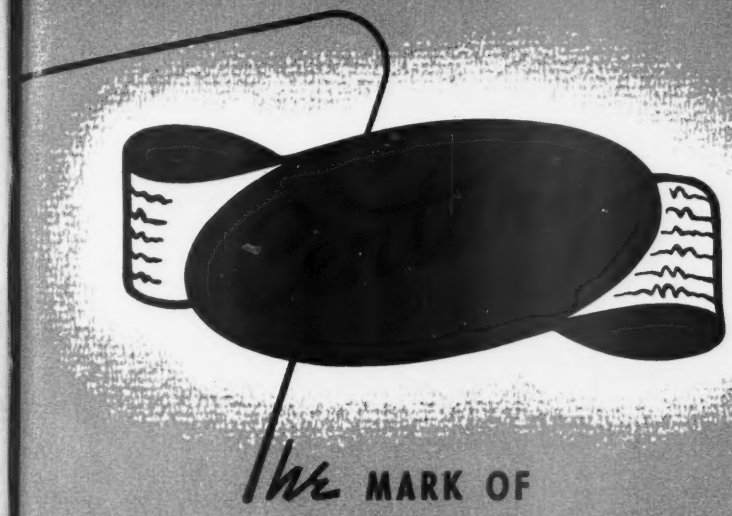

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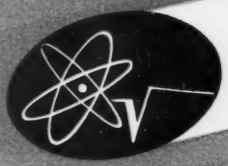

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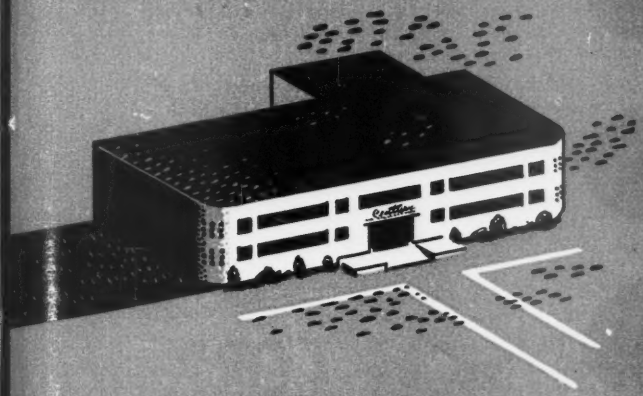

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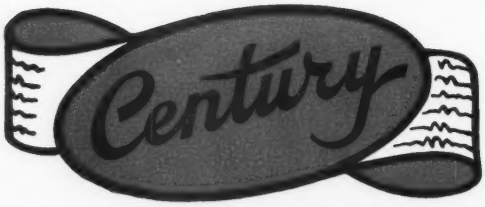

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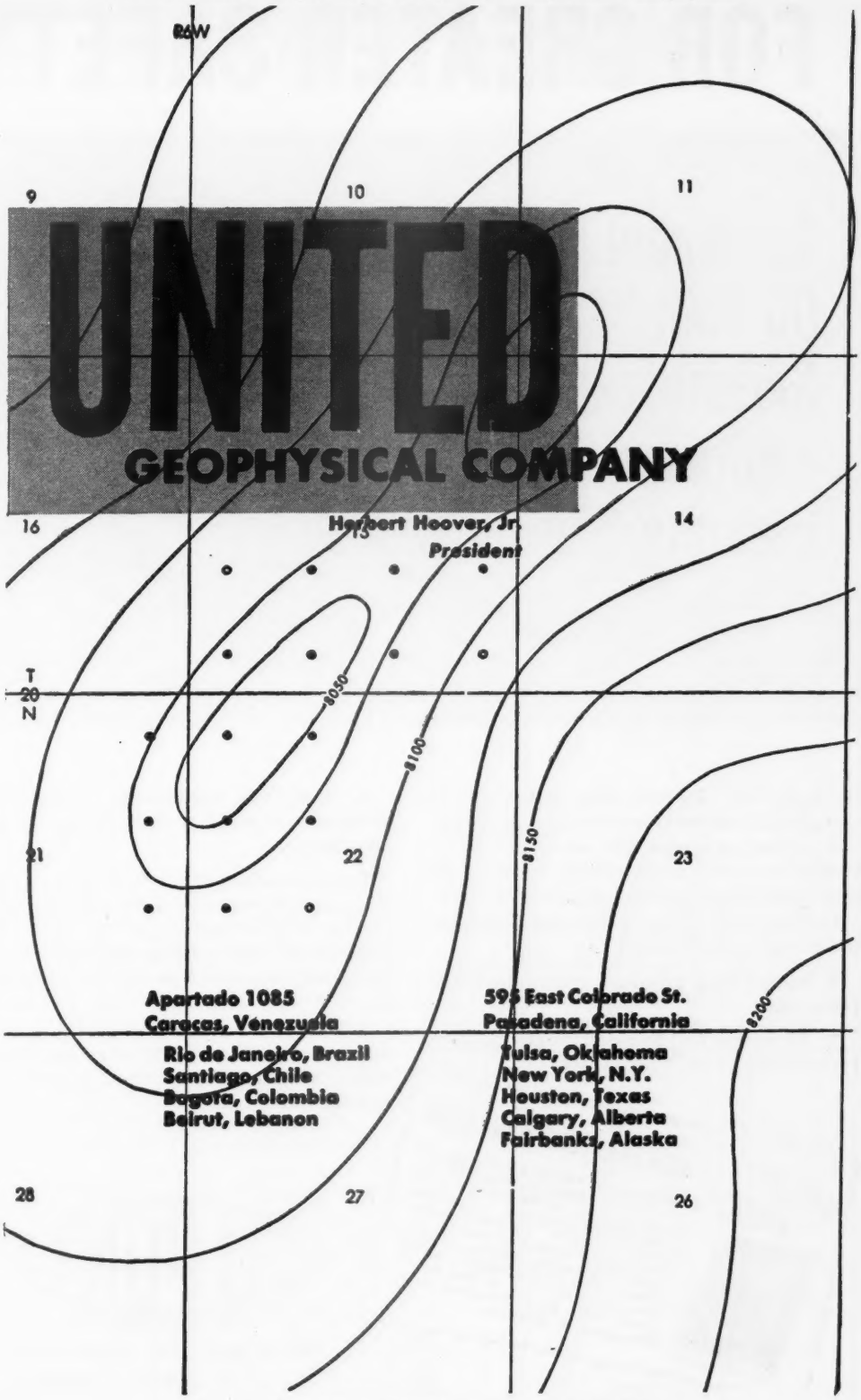
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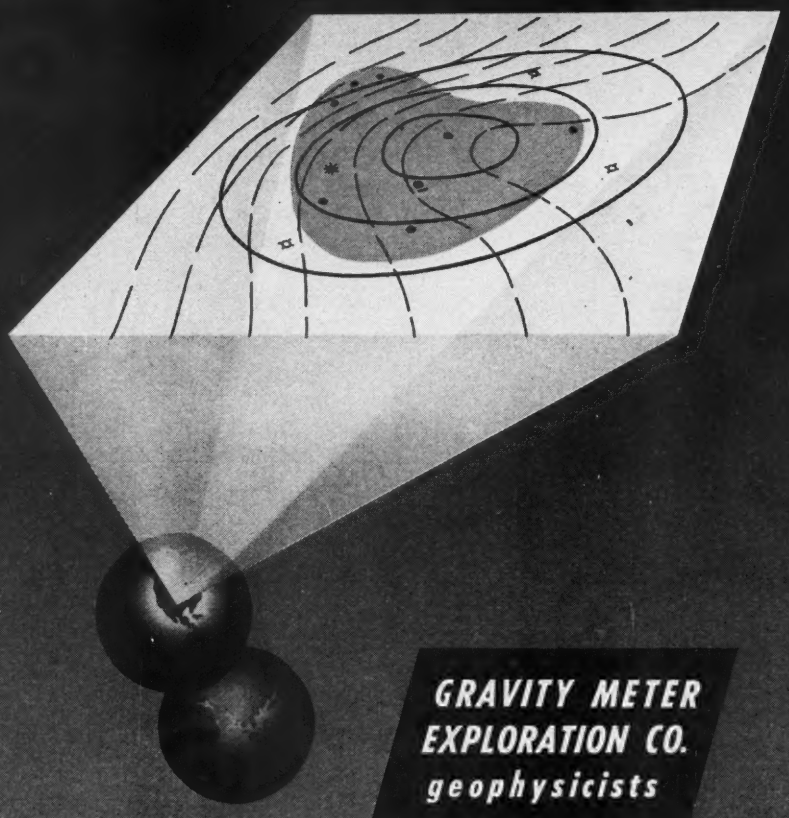

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VOLUME XIV OCTOBER, 1949 NUMBER 4

GEOPHYSICS

A Journal of General and Applied Geophysics

GEOPHYSICAL ACTIVITY IN 1948*

E. A. ECKHARDT†

GEOPHYSICAL ACTIVITY IN THE OIL INDUSTRY

The expectation expressed at our convention a year ago that geophysical activity would reach a new record high in 1948, has been amply fulfilled. For the oil industry the year 1948 was record making in many respects. At its end, the reserves of the industry stood at a new all time high, in spite of their depletion by record breaking production. The over-all exploratory effort not only replaced the oil produced but, in addition, provided a margin of over a billion barrels for the future. This report is confined to the geophysical aspects of exploration and aims to provide only a picture of its magnitude, its character and its geographic distribution.

The report of last year dealt only with the oil industry and only the work done in the United States. With the able assistance of the members of my committee and the help of many who were kind enough to furnish them and me with information, the report for this year has been broadened in two respects. It is world-wide in scope, and it includes the Mining as well as the Oil Industry.

The rise in the number of seismograph parties operating in the U. S. over the past 10 years is shown graphically in Figure 1. The number of seismograph parties has steadily risen over the past eight years at a rate averaging 14.4 percent per year. The rate of increase during 1948 was a vigorous 17.4 percent. The volume of seismograph operations in the U. S. has, in fact, more than doubled during the past eight years.

Unfortunately, figures are not available which would permit a similarly precise statement with reference to world-wide operations. However, the early part of the eight-year period included the war years during which geophysical opera-

* Report of the Committee on Geophysical Activity of the Society of Exploration Geophysicists. The members of this committee are A. A. Brant, Herbert Hoover, Jr., D. C. Skeels and E. A. Eckhardt, Chairman. Presented at the St. Louis Meeting of the Society, March 15, 1949. Manuscript received by the Editor June 21, 1949.

† Gulf Research & Development Company, Pittsburgh, Pa.

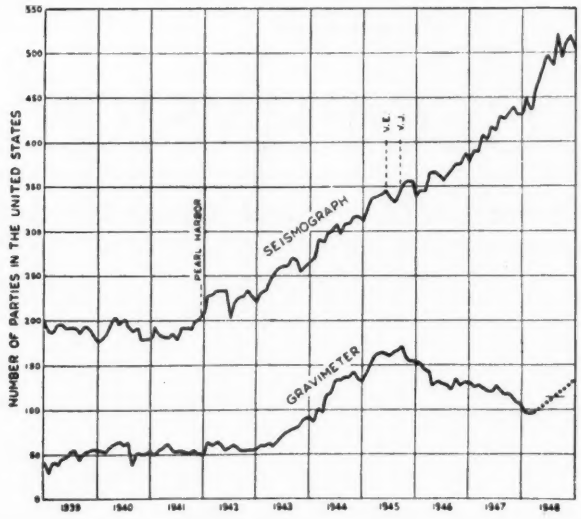

FIG. 1. Number of seismograph and gravimeter parties in the United States.

tions outside the U. S. were especially handicapped and to a considerable extent impossible. The growth in foreign operations, for several years back, must have been at a substantially greater rate than that recorded in the U. S.

The pie chart, Figure 2, shows the world distribution of seismograph activity for the year. More than 95 percent of the work was done in the Western Hemi-

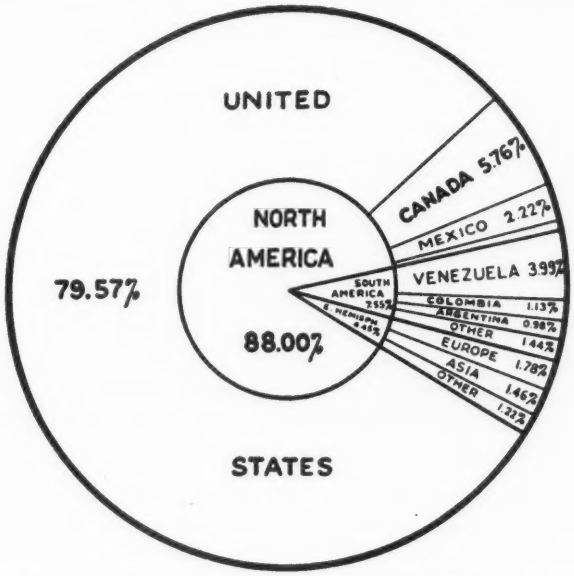

FIG. 2. World distribution of seismograph activity in 1948.

sphere, and almost 80 percent of the total was done in the U. S. Outstanding is the growth of activity in Canada, almost entirely in Alberta, where the activity in 1948 was substantially in excess of that reported for the Eastern Hemisphere and not far below the total for South America.

In Figure 3 the world distribution of gravity operations is similarly portrayed. Here the combined participation of the Eastern Hemisphere and South America is about twice as great as it was in seismograph operations. The reason for this is probably to be found in the very large amount of gravity work done in the U. S. during the past 10 or 12 years. The Eastern Hemisphere and South Amer-

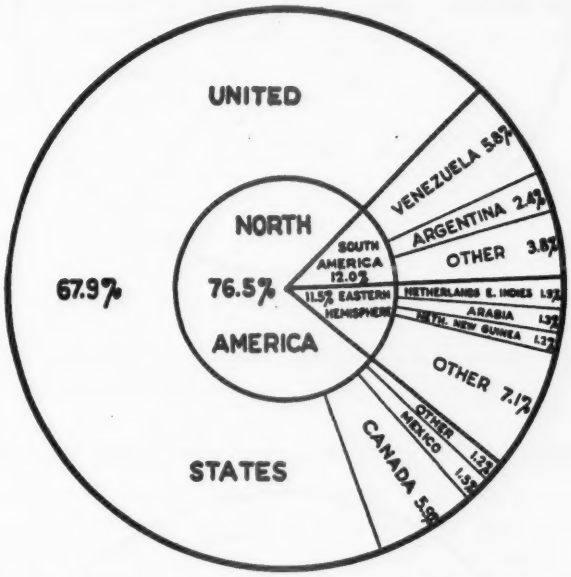

FIG. 3. World distribution of gravimeter activity in 1948.

ica are in the process of catching up. It seems likely that this process will be accelerated in the years lying immediately ahead.

Comparison of Figure 4, which presents the distribution of seismograph activity in the U. S. during 1948, with the corresponding chart for 1947 at first glance indicates little change. The contribution of Texas is slightly up, and that of Louisiana slightly down. Their combined total is slightly lower. Oklahoma, Mississippi, New Mexico and Colorado are all slightly down, but the share of Wyoming has increased so vigorously as to provide an increased total for the Rocky Mountain States. California is slightly up

The distribution of gravity operations in the U. S. in 1948, which is displayed in Figure 5 shows significant increases for both Texas and Louisiana, the increases being most marked in Coastal Louisiana and Texas outside the coastal area. The percentage participation of New Mexico and Colorado has dropped to about one-half for each compared to 1947, and this accounts for a drop in the

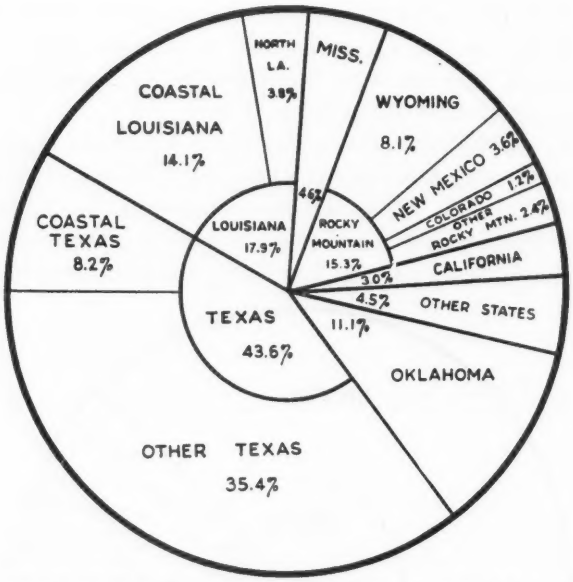

FIG. 4. Distribution of seismograph operations in the United States in 1948.

Rocky Mountain States total, although Wyoming and other Rocky Mountain States are slightly up. Mississippi is very slightly lower and Oklahoma unchanged.

The total crew months of gravity operations during 1948 were 4.1 percent

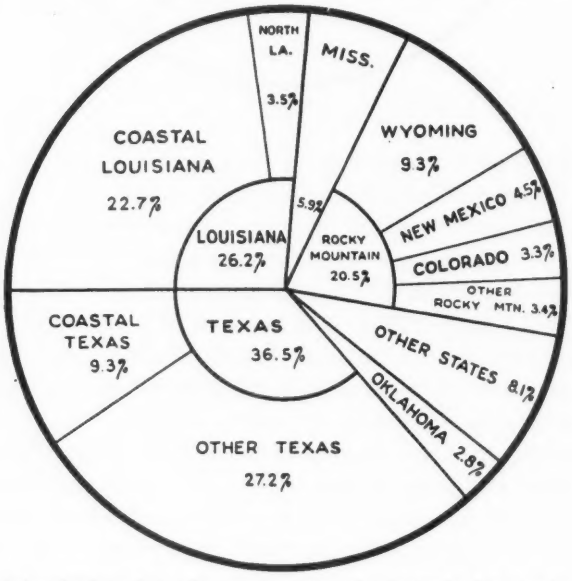

FIG. 5. Distribution of gravimeter operations in the United States in 1948.

lower than the total for 1947. Unfortunately the crew months were not available on a month-by-month basis for a part of 1948, and it was impossible to continue the gravimeter curve on the same basis as for preceding years. However, during the first quarter of 1948, the number of parties was well below the 1947 average level from which a rising trend of gravity operations for 1948, as indicated by the dotted extension of the curve, is an obvious consequence.

Measured in terms of crew-months or of dollars spent, magnetometer operations in the U. S. rank a poor third. Although operations on the ground decreased somewhat during the year, airborne operations increased in both volume and territorial spread. There were probably not over nine airborne magnetometers operating the world over at any one time, and the average number for the year was probably not over five or six. In terms of area mapped during the year, the airborne magnetometer ranks an unquestioned first. During 1948 it has mapped more area than did all the seismograph operations over the entire world and has done so at a cost less than 2 percent of the cost of all of the seismograph operations. The capacity for doing more work existed. It is very likely that the demand for airborne magnetometer surveys was limited primarily by the fact that many exploration departments were unprepared to deal with the interpretation problem.

The expenditures of the U. S. oil industry for its domestic geophysical operations in 1948 were in the neighborhood of $125 million. The increase over the $105 million of 1947 was largely due to greater volume of operations and to a lesser degree to increased costs. Of this amount, $105 millions were paid for seismograph work and the balance for gravity and other operations. With over 3 billion barrels of oil discovered during the year and taking a price of $2.00 per barrel, which is well below the average price per barrel of crude realized during 1948, the cost of the geophysical work turns out to be 2.5 cents per barrel, or about 1 percent of the value of the product. It is conceded that this figure is not a good measure of the effectiveness of geophysical methods in finding oil since not all oil is discovered as a direct, or even indirect, result of geophysical operations. But, a substantial part of the oil is discovered, directly or indirectly, as a result of geophysical work and the figure is probably not wrong by more than a factor of 2. The over-all cost of finding oil is, of course, much greater than this. It includes the cost of leases, those ultimately found productive and the greater number which are abandoned; the cost of geological work; the cost of wildcat drilling, including the cost of all dry holes, and other related items.

Our problem is to find two billion plus barrels of new oil in the U. S., year after year. To accomplish this staggering job, we must constantly review our operations to make certain that our exploration forces are always being used when and where they will do the most good. C. J. Deegan[1] has very recently published a thought provoking study of the major oil fields of the U. S. He defines a major

[1] *Oil and Gas Journal* (January 27, 1949), pp. 180–183.

field as one having an estimated ultimate production of 100 million or more barrels of oil and finds that there are 130 such fields in the U. S. As of January 1, 1949, these fields have contributed 60.5 percent of the sum of the accumulated production and the remaining U. S. reserves. In 1948 they contributed 50.2 percent of the current production. Precise figures for the total number of fields do not seem to be available, but there are at least 5,000. The major fields therefore constitute less than 3 percent of the total. They are clearly the backbone of the oil supply.

It is of interest to us when these major fields were found. The patriarch among them is the Bradford Field of Pennsylvania, discovered in 1871. Last year it produced over 11 million barrels, which is not bad after 77 years. Figure 6 shows

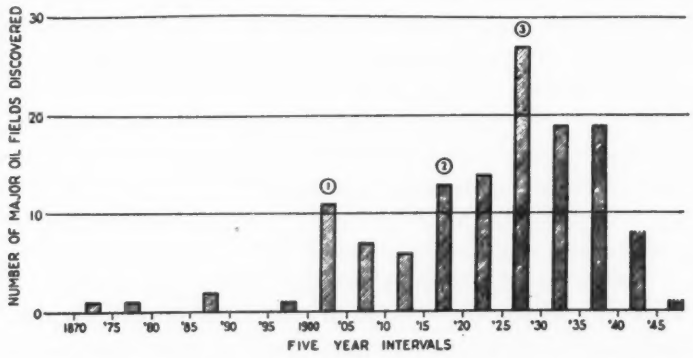

FIG. 6. Discovery time schedule major oil fields of the United States. 1. Impact of aggressive wildcatting. 2. Impact of geology. 3. Impact of geophysics.

the discovery rate of major fields by five-year intervals. Five were found before 1900. The pace was substantially accelerated in the early years of the present century when aggressive wildcatting brought results. The pace was stepped up further in the 1915–1919 interval, when the oil companies discovered geology, and the latest step up came 1925–1929, when the geophysicists discovered the oil companies. Each development established a higher level of discoveries.

As the years pass, this chart will require modification, especially for the later years. The reason for this is illustrated by the Rangely Field which, although discovered in 1917, did not attain the status of a major field until almost 30 years later. Other fields discovered in the forties, or perhaps even in the thirties, which are now in the minor classification, will at some later date turn out to be major oil fields and will be so credited in the year of their original discovery.

Not all problems confronting us can be put into mathematical form, but usually something can be learned by trying to do so. One hundred and thirty major oil fields have been found in the U. S. and an unknown number x remain to be discovered. Though unknown, this number is definite and it includes the fields already found which, though now believed to be small, will later be recognized

as major fields. The opportunity at the beginning was $130+x$ and at the beginning of this year it was x minus the number now known which, over the years, will be graduated from the minor to the major class. No one knows and perhaps no one can even make an intelligent guess as to the magnitude of this number. If we could know, we could measure our chances of finding a major oil field this year, next year, or some other year in the future.

We do know, however, that, having found 130 major oil fields, the number remaining to be found has been appreciably, perhaps substantially, diminished. We also know that as our opportunities diminish the cost of an achievement is going to rise. The economic law of diminishing returns has operated, does operate, and will continue to operate in exploration as it does in all other fields of human activity. The only way in which its harshness can be ameliorated is by employing all means which are available or which can be conceived to reduce the odds against you. In this the possibilities are far from being exhausted.

The advantage to be gained from a further increase in the volume of geophysical work is problematical, but that to be gained by better integration of the overall exploratory effort is likely to be much more rewarding. This is not to say that the former may not be fully warranted, but I would put my money on the latter as the most promising approach to the economical and expeditious discovery of future oil fields, large or small.

GEOPHYSICAL ACTIVITY IN THE MINING INDUSTRY

For the first time this report includes data on the geophysical activity in the Mining Industry, for the year 1948. The data received are believed to be 90 percent complete for Canada, Australia and India, about 75 percent complete for the U. S. and less complete for Africa, Europe and South America. There are no recent data for Russia. The Mining Industry appears to have no organized facilities for the accumulation of such data, and the achievement of a relatively complete report will take considerably more doing than was necessary in the Oil Industry. Once the Mining Industry recognizes the value it can derive from a composite record of its activities in which the activities of individual companies remain completely anonymous, it is anticipated that this report will become just as complete and informative as the parallel record in Petroleum.

The data available indicate that in 1948 the world-wide expenditures of the Mining Industry for geophysical operations and research were approximately two million dollars. It is to be noted that about 17 percent of these expenditures were for research and experimental surveys.

The world-wide distribution of the operations is shown in Figure 7, which indicates Canada to be the outstanding leader in the use of geophysics in prospecting for metallic minerals. Its share is almost half of the total. It is astonishing that the U. S., which stands so far out in front in the use of geophysics in prospecting for petroleum, ranks so poor a second in its use by the Mining Industry.

Another fact peculiar to the mining geophysics picture is the degree of govern-

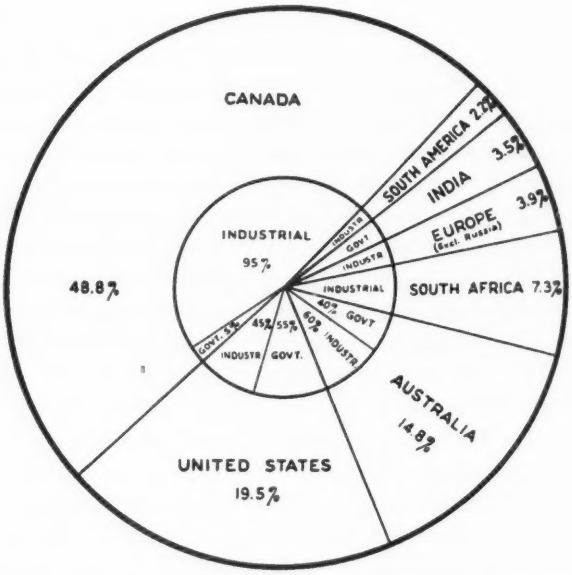

FIG. 7. World distribution of geophysical operations in mining in 1948.

ment participation. More than half the work in the U. S. was done by or for the Government. Of the total work reported over 22 percent was for the account of governments, and therefore at the expense of the taxpayer.

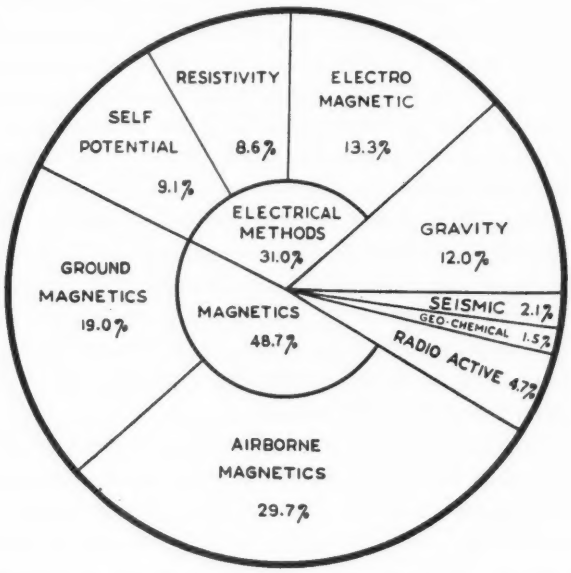

FIG. 8. World distribution of geophysical work in mining, by methods, in 1948.

The distribution among the various geophysical methods used in 1948 in mining is shown graphically in Figure 8. Almost half the expenditures were for magnetic surveys, of which the greatest share went for airborne surveys. The latter are, unfortunately, not available, economically, in small packages but if the requirements are large enough, the cost per unit length of profile is very attractive. Electrical methods accounted for 31 percent of the total, and gravity surveys for 12 percent.

In terms of the value of annual mineral production, the cost of the mining geophysical work in Canada for 1948 is estimated at 0.25 percent and at 0.025 percent in the U. S. Since this figure was a little over 1 percent for petroleum geophysical work, it may be profitable for those directly concerned to consider whether the Mining Industry is spending too little or the Oil Industry is spending too much on geophysical work.

GEOPHYSICAL EXPLORATION FOR LIMESTONE REEFS*

F. J. AGNICH†

ABSTRACT

Various geophysical methods are discussed in relation to their possible value in locating limestone reefs, with special emphasis on the gravity meter and seismograph. The effects of possible velocity variations through reefs on reflections from below a reef body are examined. Relationships between the shallow and deep horizons indicate that time isopach maps of such seismic data are extremely valuable. A suggested exploration procedure describes several detailing methods, and emphasizes the important role of the interpreter in solving the problems associated with exploration for limestone reefs.

INTRODUCTION

The present great interest in oil production from limestone reefs has made it essential that we examine methods of exploration in order to seek to determine which methods can be used to greatest advantage in locating such fields in the future. The purpose of this paper is, therefore, to endeavor not only to evaluate the data accumulated in the past, but, more important, to intensify the study of the problems involved in reef location.

DEFINITIONS

The first essential to the discussion of any topic is a definition. A great deal of confusion has arisen in the past, and still exists, because of a much too free use of the term "reef." The term "reef" as broadly used can denote a great variety of things including certain types of igneous veins and ore deposits. By title this paper is limited to discussion of limestone beds, but we are obliged to carry the definition even further since there are many varieties of limestone which cannot be classed as reef deposits. In general, limestones can be divided into two groups inorganic, and organic. The reef limestones fall into the latter category but even here some further definition is necessary. Adams[1] has made a very apt distinction in which he refers to a "profile of equilibrium." This term is applied to limit the use of the word "reef" to those limestones which are built up above the bottom of the sea on solid foundations, one organism atop another, in defiance of the sorting action of waves and currents. Thus, the flat or tabular limestones, even where they occur in a section which has graded from sands or shales into limestones and thus present, perhaps, an irregular horizontal extent, are not considered to be reefs. Also excluded are those cases in which a change in porosity in an essentially flat bodied limestone provides a stratigraphic trap.

* Presented at the Annual Meeting of the Society, St. Louis, March 15, 1949. Manuscript received by the Editor June 23, 1949.

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[1] J. E. Adams, "Origin, Migration, and Accumulation of Petroleum in Limestone Reservoirs in the Western United States and Canada," *Problems of Petroleum Geology* (1934), pp. 357–358.

In summation, the term "limestone reef" shall include only those organic limestones which were built up above the general level of the sea bottom in defiance of the sorting action of waves and currents which are the determining factor of the level, or "profile of equilibrium" of such a sea bottom.

STRUCTURAL RELATIONS

A schematic diagram, illustrating the local structural conditions which appear to be normally related to reefs, is shown in Figure 1. Two important structural relationships are evident. First, the beds above the reef show folding due to differential compaction and the amount of the folding decreases rather rapidly as the beds become shallower. The importance of this shallow structural effect will be discussed later. Second, the beds beneath the reef are shown to have normal

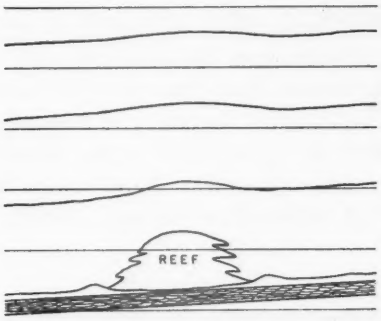

FIG. 1. A schematic diagram illustrating the local structural conditions which appear to be normally related to reefs.

dip without any apparent structural relationship to the reef itself. This absence of deep local structure is borne out by deep drilling in many reef fields including Eskota and Seymour in Texas, and The Marine Pool in Illinois. While there may be some exceptions, the author believes that we can usually expect the beds below a reef to exhibit normal dip and that there is rarely any relationship of deep local structure to reefing. This statement should not be construed to imply that no relation between reefing and regional structure exists. Large regional uplifts whose flanks provided the floors of shallow seas are ideal locations for reef formation and, in some cases, the greatest reef developments may occur on the crests of such regional structures.

One example is the Red River Uplift in north-central Texas where impressive reef build-ups occur on the crest of that uplift. However, the greatest reef thicknesses do not usually occur over the highest part of the uplift and the great irregularities of the reef development are not necessarily reflected by similar irregularities of the uplift. It is probable that during Canyon time this uplift was slowly being submerged and the reef development progressed up the flanks and finally over the crest until, eventually, submergence became too rapid and the reef or-

ganisms were killed by excessive depth of water. The author suspects that this same situation occurs over the Matador Arch which is, of course, the western extension of the Red River Uplift.

This relationship of reefing to the paleogeography at the time of reef formation cannot be ignored. The first step in any exploration program directed toward reef location should be a study of the paleogeography of the area in order to localize the areas to be subsequently examined by geophysical methods.

APPRAISAL OF POTENTIAL EXPLORATION METHODS

Of the various geophysical methods available to us, the gravity meter and the seismograph appear to have the greatest potentialities as tools to aid in the location of limestone reefs. The various electrical methods do not appear to have enough penetration to explore the depths at which reefs are normally found. The magnetometer is also of dubious value inasmuch as magnetic effects over sedimentary structures are usually very small unless some corresponding anomaly in the basement rocks is present. Reef limestones are quite pure and have a very low magnetic susceptibility. It may therefore be possible that where such a body is surrounded by sediments of higher than normal magnetic effects, a very close detailed survey might show some effect. Some magnetic surveying of possible reefs is now being done but the results so far are inconclusive.

GRAVITY METER

An adequate appraisal of the value of the gravity meter in locating reefs is hardly possible at the present time due to the small amount of drilling that has been done on gravity anomalies which are thought to indicate reefing. The next few months should serve to give an appreciably greater amount of information in this respect.

In discussing the gravity effects over reefs with various gravity specialists, the author found that no great unanimity of thought exists on the subject. Indeed, there is a division of opinion as to whether or not reefs will show up as maxima or minima. One approach to the problem, however, is to examine the relative densities of the rocks involved. This should be of particular value in that we normally do not find, nor should we expect, deep structure below reefs. Thus, in the majority of cases, we can eliminate all effects except those of the relative densities of the reef material and the surrounding sediments.

The density values given in Table 1 have been compiled from a number of sources and represent a fair average of the observations noted. The most significant feature of this table is the wide variation given for shale densities. This variation is due almost entirely to the great compaction of shales resulting from overburden. Athy[2] has shown that there exists a very direct relationship between

[2] L. F. Athy, "Compaction and Its Effect on Local Structure," *Problems of Petroleum Geology* (1934), pp. 813–819.

depth of burial and density of shales which he has represented in graphical form. The figure of 1.4 is the density of near-surface muds; and the higher value of 2.6, the density of shale at depths of 4,000 to 5,000 feet. This relationship of density to depth is absent in sands and limestones.

Thus we can draw the conclusion that the density of the sediments surrounding a limestone reef body will approach the density of a normal limestone as the depth increases. At depths of 4,000 feet or greater the densities may be possibly on the order of 2.5 for the sediments surrounding the reef and 2.6 for a normal limestone.

In addition, another very important factor is present in that the porosity of reef limestones is generally much greater than that of the chemical limestones and limestone clastics. The author has been unable to find any direct measurements

TABLE 1

A COMPARISON OF LIMESTONE DENSITY WITH DENSITIES OF TYPICAL SEDIMENTS

Rock	*Average Density*
Clay and Shale	1.4 to 2.6
Sand	2.0 to 2.5
Limestone	2.5 to 2.7

of porosities in reef limestones compared to other types of limestone, and therefore cannot give a quantitative relationship. However, there are so many references to the extremely high porosity of reef limestones in the literature that we must at least assign a qualitative relationship and say that reef limestones are usually much more porous than are the other types of limestone. Indeed, the porosity of some of the reefs is so high as to be almost cavernous. Cores taken in wells in the Vealmoor Reef normally give a small yield which in some cases has amounted to less than two feet of material from a 20-foot core.[3] This great porosity will serve to diminish the density of the reef material appreciably and, in many cases, even to lower it to less than the density of the surrounding rocks.

There may also, however, be a relationship between reef thickness and density. Conselman and Conley[4] have pointed out that wide variations in porosity are present within a reef due to crushing under load, recementation or local primary chemical deposition; and these processes will, of course, tend to increase density. While the porosity is subject to wide local variation, the author believes that, in general, a decrease in porosity with depth within the reef is present. This is borne out to some extent by seismic velocity variations which are discussed later.

[3] H. C. McCarver, Personal communication on Vealmoor Reef, Howard County, Texas.

[4] Frank B. Conselman and J. N. Conley, "Limestone Development in the Pennsylvanian of the Eastern Permian Basin," presented at the Joint Regional Exploration Meeting of the Dallas Geological Society and the Dallas Geophysical Society, Dallas, Texas, November 18, 1948.

It thus appears that the type of gravity effect observed is dependent upon the depth, thickness, and porosity of the reef. Since all of these factors are subject to extreme variation, we can well expect anomalies to vary from maxima to minima.

The relative densities of the reef and surrounding materials should be given extensive study. Such examination may establish some relationship between density of reefs and regional location or geologic age and would be of great value as an aid to reef location by the gravity meter.

SEISMOGRAPH

Velocity Considerations

We do not have many determinations of reef velocities and those available are subject to wide differences of opinion. Before attempting to come to any conclusions as to known variations in reef velocities, it is necessary to again refer to a definition of reef limestones. The same velocity survey in a reef well can have wide variations in interpretation, depending upon how much of the section involved is considered to be reef material. If we adhere to the rigid definition proposed earlier in this paper, we will come out with a lower velocity figure than if we include all the limestone in the immediate section under consideration where it may include considerable thicknesses of normal limestone beds. This error is quite likely to occur in those cases where the reef appears to be based directly on a limestone bed with little or no clastic material between the two, as is commonly the case, for example, in Palo Pinto reefs.

A velocity survey in a reef well in west central Texas illustrates this point. The well penetrated a thickness of almost 900 feet of reef limestone and then went directly into a small thickness of oolitic lime underlain by a normal thickness of Palo Pinto limestone. The interval velocity in the reef material is about 16,000 feet per second while the velocity of the lime below the reef is about 19,000 feet per second. If the whole section is considered to be reef material, the interval velocity is found to be 17,000 feet per second. The reef velocity is not raised very much in this case since the reef is of much greater thickness than is the normal Palo Pinto limestone. In those cases where the reef occupies only a small upper portion of a thick limestone section, the velocity assigned to the reef will be raised to a much higher figure if the whole section is included in the interval used.

A well in the Permian Basin in west Texas shows this velocity contrast to a greater extent. The upper 1000 feet has an interval velocity of about 17,000 feet per second, while for the lower 500 feet, an interval velocity of over 21,000 feet per second applies. The velocity for reef material here is again directly dependent upon just how much of the section is considered to be reefing, and how much called normal limestone.

Another survey in west central Texas shows a thin reef section having an apparent velocity of 23,000 feet per second, which was the highest figure noted.

A recent velocity survey in a well in deep west Texas indicates that appreci-

able velocity variations can exist in the reef body. The upper 300 feet has an interval velocity of only slightly over 10,000 feet per second, while the lower portion has an interval velocity of over 20,000 feet per second.

On the basis of the few wells available, we can come to two conclusions: (1) that the upper section of a reef has a much lower velocity than the lower section, and, (2) that the average velocity of a reef body is lower than the velocity of a normal limestone of approximately the same age and depth. In any additional surveys the amount of reef material should be carefully determined beforehand; then shots should be taken with the geophone located at the top of the reef and at the contact between the reef material and the normal limestone. A velocity of 17,000 feet per second is applied to reef material in the illustrations accompanying this paper. This velocity will no doubt be considered too high by some and too low by others and is an attempt to strike a happy medium.

The velocities of the material surrounding the reef vary considerably depending upon the type of sediments involved. Except in those cases where the off-reef sediments are predominately limestone, the reef material will usually have a considerably higher velocity. One exception was noted in a well in west central Texas where the reef limestone velocity does not seem to be appreciably higher than the velocity of the shale which lies off the reef. As will be brought out later, the velocity contrast between reef and off-reef materials is of great importance in reef exploration by the seismograph.

Refraction Method

The use of the refraction seismograph in reef location is not new, as considerable success was obtained in the late 1920's in New Mexico.[5] Since that time, however, little refraction work has been done except on the Edwards Plateau and recently in New Mexico. The author is not aware of any refraction shooting being done in other areas expressly for reef location, but certainly the method should be tried, particularly in those areas where sufficient velocity contrast between the reef and surrounding material exists. The greatest drawbacks to the use of refractions are the usually small size of the reefs and, particularly in west Texas, the relatively great depth to the reefs. In addition, the presence of high-speed limestone beds in the section above the reef may serve to "mask-out" any possibility of obtaining a refracted wave from the reef surface itself. Nevertheless one suggestion is to use a fan-type arrangement such as that used in salt dome location and to plot minimum times from waves refracted from a horizon deeper than the reef.

An illustration of travel path relations for a refracted wave passing through a reef as compared to a wave refracted from the same horizon and passing through a section without a reef is shown in Figure 2. Keeping the shot to detector distance constant, as would be the case in a fan type arrangement, and using 17,000

[5] A. I. Innes, Personal communication.

feet per second as the reef velocity and 12,000 feet per second as the velocity of the material surrounding the reef, for the conditions shown we find a difference of 22 milliseconds between the two paths. This difference is rather small, particularly if the area is complicated by any severe weathering or topographic differences. Also appreciable dips in the beds through which the waves pass would complicate matters. If a shot-to-detector distance of correct length is used it may be possible to record a second event coming from a bed above the reef. The time differences observed in such an event could then be used to correct for weathering and topographic differences and for normal dip.

The velocities used in this illustration would be a fair average for west central Texas but the 12,000 feet per second, in particular, may be too low for other areas.

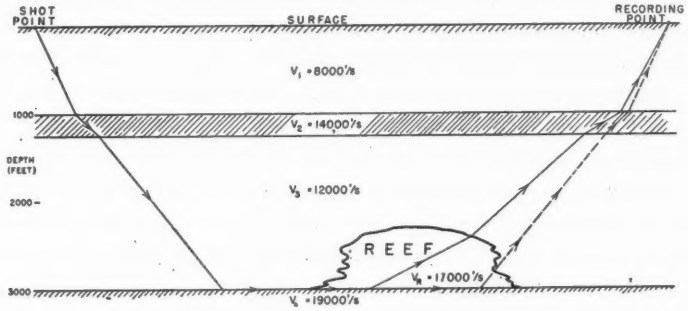

FIG. 2. An illustration of travel path relations for refracted wave passing through a reef as compared to a wave refracted from same horizon and passing through a section without a reef.

If this velocity were 13,000 feet per second, and the reef velocity the same (17,000 feet per second), the time difference would be reduced to 16 milliseconds. Also, if the reef thickness were 200 feet less than shown, the difference would be 11 milliseconds. Conversely, higher reef velocities and reef thicknesses would show greater differences. We can thus infer that the effectiveness of refractions in reef location will be dependent upon both the thickness of the reef and the velocity differential between the reef and the surrounding materials.

Reflection Method

The greatest success in locating reefs in recent years has come about by use of the reflection seismograph. In many cases, however, the surveys mapped shallow structure over the reef or an erroneous deep structure. Subsequent drilling of these features proved presence of a reef much to the surprise and, usually, the delight of everyone concerned. In some areas, such as in north Texas in Throckmorton, Young, and Archer Counties, small reef build-ups in the Caddo usually provide excellent reflecting surfaces and their location is merely a matter of providing great density of control. In some cases, also, the reefs on the Red River Uplift are mappable directly. Where reflections are obtainable from reef surface, the problems involved are not greatly different than those encountered in map-

ping normal structures and need not be discussed here. Generally, and particularly in west Texas and west central Texas, we are not able to obtain reflections of usable quality from the reef surface itself. Since the reef surface usually presents an excellent velocity interface, this inability to secure usable reflections must be ascribed to other factors; one of which may be the great irregularity of the reef

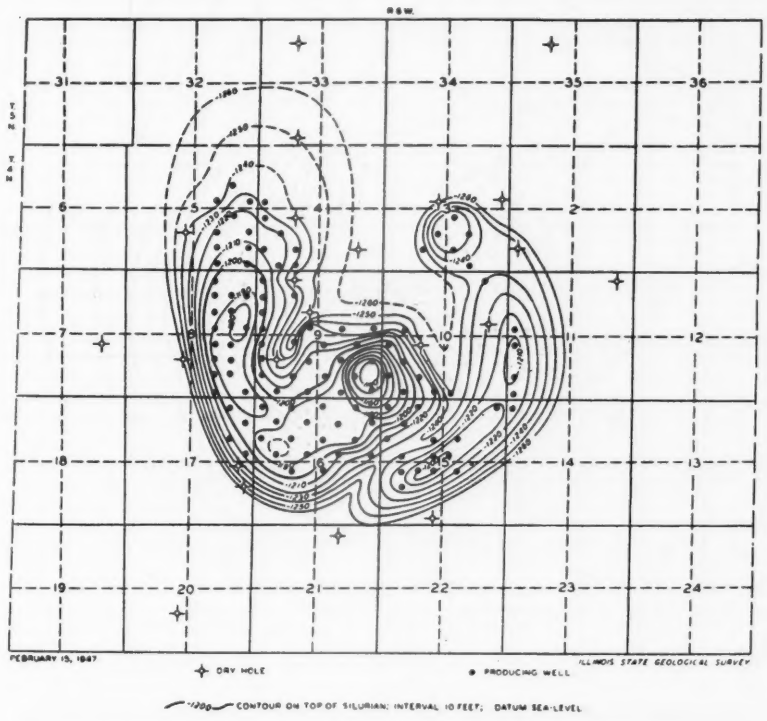

FIG. 3. Structure of surface of reef, or top of Silurian, Marine Pool. Note deep channel in reef.

surface itself. Most of the time, we shall have to work at the problem of reef location in an indirect manner and will have to interpret the data so obtained with an eye to the effects caused by reefs. Since reef effects vary considerably in different regions, it is necessary to examine the type of effect to expect when shooting over a reef in any given area, so that we will know what to look for.

The amount of compactional folding over a reef varies considerably and is dependent upon the vertical extent of the reef and upon the nature of off-reef materials. The variations in density of the rocks shown in Table 1 are again important since they show directly the amount of compaction which will occur. The effect of burial on sands and limestones is very slight, and in fact, it is doubtful that any compaction occurs after the materials are sorted at the time of deposition and after possible solution effects at time of shallow burial. The shales,

however, respond readily to compaction as has been shown by Athy[6] and others. Therefore, in areas where the off-reef sediments are predominantly shales, we can expect to have very appreciable structure developed above the reef due to differential compaction. Also, the greater the depth to the reef, the greater the amount

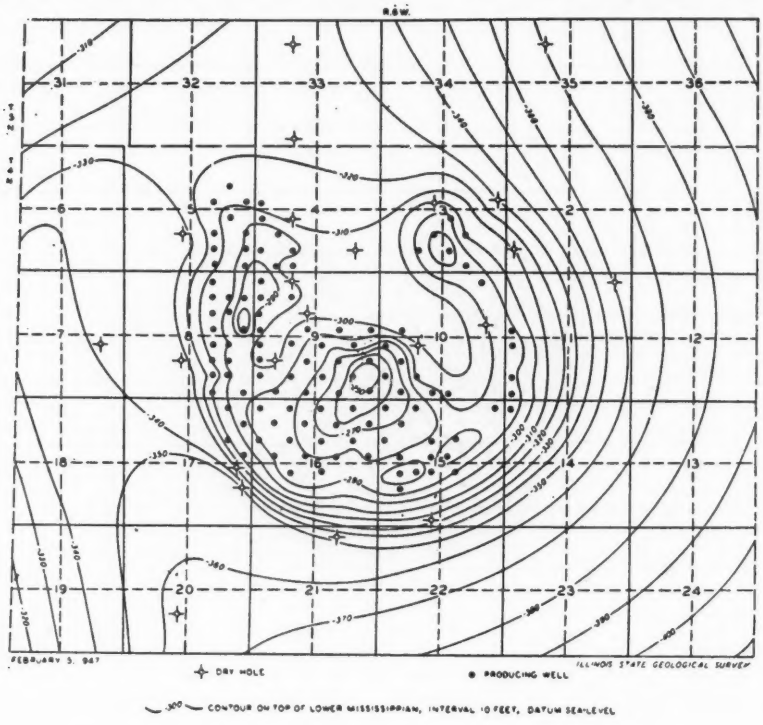

FIG. 4. Structure 900 feet above reef, or top of Lower Mississippian surface, Marine Pool. Note modified channel effect.

of compaction present. This structural effect will be very slight or entirely absent where the reef is surrounded by sands or limestone. Thus a study of the off-reef sediments around known reefs in the area to be explored is a necessity in order to know whether or not to assign any significance, as far as reefs are concerned, to small shallow closed areas.

Two examples of shallow closure over reefs are the Vealmoor Field in Howard County, Texas, and the Marine Pool in Galena County, Illinois. In a discussion of the latter pool, Lowenstam[7] presents several plates showing compaction effects over a reef. Figures 3, 4, and 5 are direct reproductions of those plates.[8] Figure

[6] *Op. cit.*

[7] H. A. Lowenstam, "Marine Pool, Madison County, Illinois, Silurian Reef Producer," *Structure of Typical American Oilfields*, III, 153–188.

[8] Through courtesy of The American Association of Petroleum Geologists.

3 shows the structure of the surface of the reef, or top of Silurian, and indicates a closure of about 120 feet. Note particularly the deep channel shown in the reef. Figure 4 depicts the structure on the top of the Lower Mississippian surface 900 feet above the reef. The closure at this depth is about 70 feet and is due, apparently, entirely to differential compaction. It will be observed that the effect of the deep channel is still present but considerably modified. The structure shown in Figure 5 is on the Lower Pennsylvanian Seahorne Limestone, about 1,000 feet

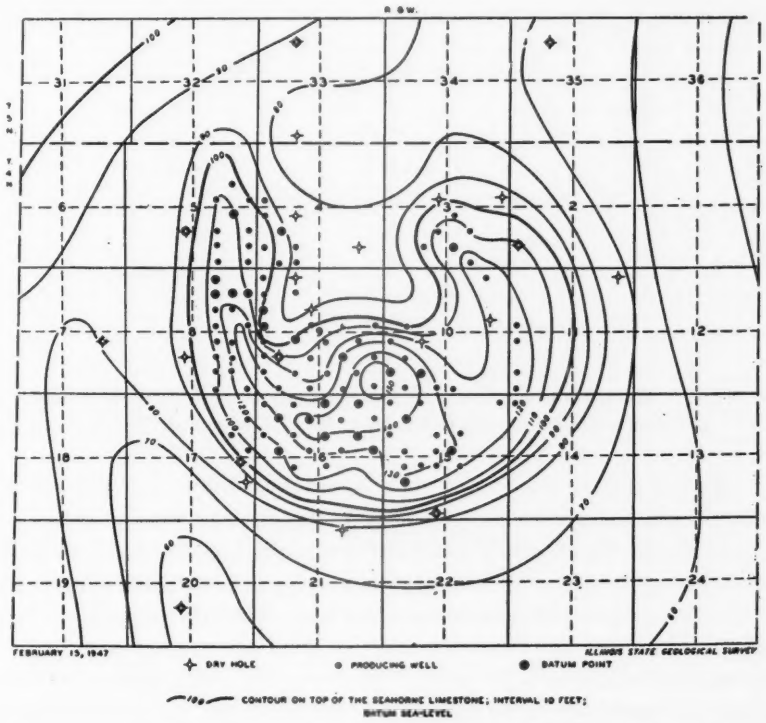
FEBRUARY 15, 1947
ILLINOIS STATE GEOLOGICAL SURVEY
DRY HOLE
PRODUCING WELL
DATUM POINT
CONTOUR ON TOP OF THE SEAHORNE LIMESTONE; INTERVAL 10 FEET; DATUM SEA-LEVEL

FIG. 5. Structure 1,000 feet above reef, or top of Lower Pennsylvanian Seahorne limestone, Marine Pool. Note further smoothing of channel.

above the reef. The closure is about 60 feet, indicating a smaller effect of compaction. The deep channel is still present but has been smoothed out even more than on the lower bed.

We can expect that shallow structure mapped over a reef will follow in general the contours of the reef surface but will modify any sharp indentations or channels. In developmental drilling of a reef field based on a shallow seismograph map, it will be necessary to pay strict attention to irregularities in contours, as they will probably indicate the presence of much greater relief on the reef surface itself.

According to Lowenstam[9] a deep Trenton high under this field was mapped by a seismograph survey and was later proved erroneous by deep drilling. The high was due to the velocity effect of the reef material. This effect is commonly present and will occur whenever the velocity in the reef is higher than that in the surrounding sediments.

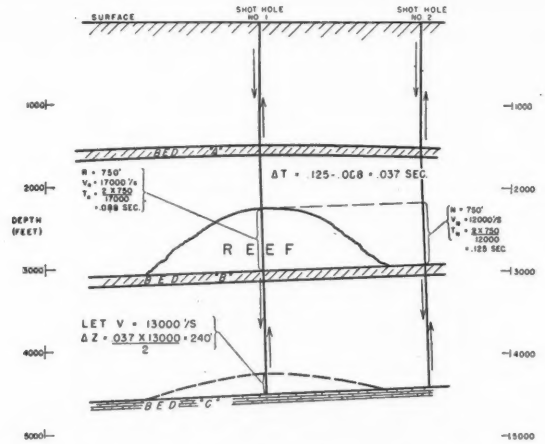

FIG. 6. Sketch showing effect of reef on reflection times. In such cases false anomalies may be mapped, such as depicted here on Bed "C."

The effect of reef velocity on deep reflections is shown in schematic diagram, Figure 6. Assuming velocities of 17,000 feet per second for the reef and 12,000 feet per second for the off-reef section and a reef thickness of 750 feet we find that the wave through the reef will show 37 milliseconds less time than a wave, reflected from the same bed, which does not pass through the reef. If an average velocity of 13,000 feet per second is used for computing reflection depths, an apparent closure of 240 feet will result. The amount of closure which will appear is dependent, of course, upon the reef thickness and on the velocity contrast.

A survey over a reef which is surrounded by a shale section will therefore be difficult to interpret as a reef since both shallow and deep structure will appear and an isopach between a shallow and a deep horizon will show the normal thinning expected over a deep structure.

In west central Texas, reefs such as the Avoca, Eskota and Seymour pools show little structure above the reef. Usually the only effect is a gentle nose. The reefs have a considerably greater velocity than the off-reef sediments, and deep reflections exhibit false closure due to this velocity contrast. A time isopach map between a shallow and a deep reflection will thus show an amount of thinning much greater than would be expected in this area. The results of the survey can then be interpreted as definitely indicating reefing. This is of some importance

[9] *Op. cit.*

since the recognition of reef probability will justify testing by drilling. This might not be the case otherwise due to the disappointing results of Ellenburger production in this area in the past.

Over large areas of west central Texas it is difficult, to almost impossible, to obtain a continuous deep reflection. It will be imperative that any scattered deep reflections obtained be closely examined for evidence of abnormally steep dips. Where these steep dips are indicated under shallow noses, parallel lines should be run to attempt to obtain added confirmation. The additional lines should be not over 1,000 feet apart because of the usually small areal extent of the reefs. If such

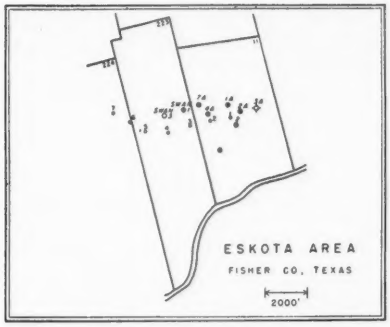

FIG. 7. Location plat of Eskota Field, Fisher County, Texas, showing seismic line shot and wells used in cross section across reef.

additional confirmation is obtained, the immediate area should be very closely detailed and isopach maps constructed between shallow and deep horizons even where the latter is based on a "phantom" constructed from dip segments. If appreciable thinning is shown by such a map, drilling is justified. Work of this nature will require a good deal of courage on the part of the geophysicist, since he will have to "stick his neck out" at times on very slim evidence. An appreciation of the difficult nature of reef work will be necessary on the part of the geologists appraising the results of such a survey.

The next two illustrations show actual examples of the effects to be expected under a reef in this area. The survey shown was performed as an experiment after the reef was discovered; and while the results are inconclusive due to insufficient shooting, they nevertheless show a definite relationship of steep dip to reefing.

Figure 7 is a location plat of the Eskota Field in Fisher County, Texas, showing the line shot and the wells used in the cross section across the reef. It may be noted that the line starts in the center of the field and runs down the west flank but does not extend over the east flank.

In the seismic cross section, Figure 8, the circles represent the computed depths to reflection points. Solid lines between these circles indicate that the quality of the reflection was good to fair. Dashed lines indicate poor to question-

able data. The heavy black line shows the surface of the reef as found in the wells, and the line below indicates the oil-water contact. The shallow reflection shows slightly more than normal dip, but the deep reflection has considerably more than normal dip. Two deep wells indicate strongly that no appreciable structure is present below the reef. The 190 feet of thinning shown between the two continuous beds is much greater than would be expected in this area and represents the type of effect to be expected in a reef survey. The Eskota Field has two reefs, the one shown being a Palo Pinto Reef while a deeper Strawn reef is also present

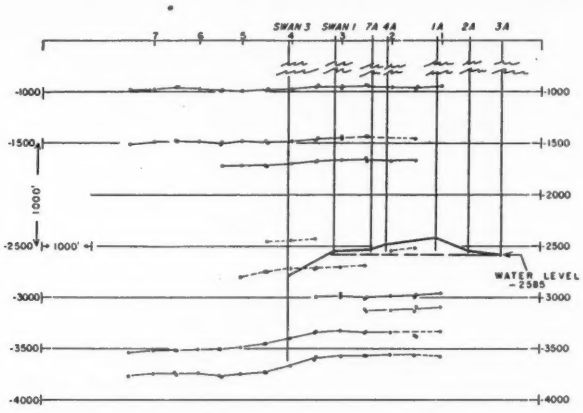

FIG. 8. Cross section of line of control across Eskota reef.

but has been unproductive so far. Of interest is the fact that the deep horizon is essentially flat under the producing wells and does not reflect the dip of the Palo Pinto reef. This could be interpreted to indicate that the highest part of the Strawn reef lies under the west edge of the Palo Pinto reef. The recently completed Swan No. 3 well topped the Palo Pinto reef too low to produce, as had been indicated by the deep reflections. The west flank of the reef is much steeper than the dip of the deep reflections, as would be expected if the steep dip of the reflections, is due to a velocity anomaly caused by the reef.

In those cases where no appreciable velocity contrast exists between reef and off-reef materials and where shallow folding due to compaction is present, an isopach between a horizon above the reef and one below the reef, will show a thick section. The presence of such a thick section below a shallow fold will be strongly indicative of reefing. In any event, isopach maps should be constructed between a horizon above the possible reef section and a horizon below that section. The isopach should be kept up to date as the survey progresses and not, as is too often the case, constructed after the survey is completed and the crew has moved to some other location. Such a map should be used as a guide to determine where additional lines are needed and to localize detailed shooting.

Reef Delineation Method

Quite often a well penetrates a reef section which is barren of oil, and it is desirable to ascertain, if possible, whether or not some higher point exists on the reef. The determination of higher points on the reef is also important where a well encounters a thin producing section in a reef, in order to avoid drilling several dry holes in trying to establish additional production. Figure 9 illustrates a method of determining whether or not such higher points exist. This is a schematic

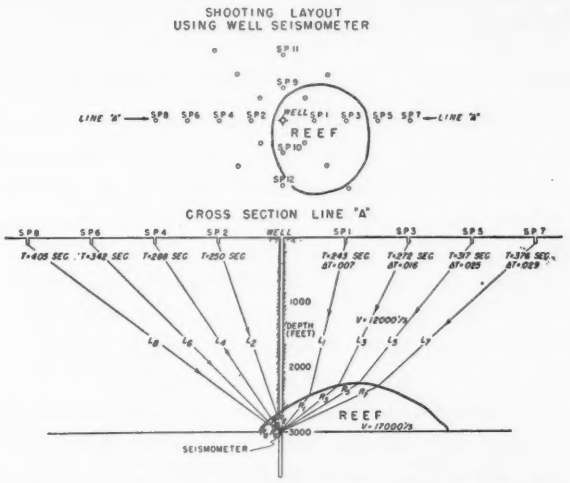

FIG. 9. Schematic diagram of shooting layout utilizing geophone in reef well to delineate reef surface or boundaries.

diagram of a well which has penetrated the edge of a reef. By lowering a geophone to the base of the reef section and shooting holes spaced around the well it should be possible to determine at least in which direction the reef surface rises. This will be true only if sufficient velocity contrast exists. In the diagram shown here, using the velocities and reef thickness indicated, differences in travel times from shot holes equidistant from the well would be as much as 30 milliseconds. A surface plat showing suggested shot hole arrangements appears in the upper part of the drawing. A series of holes spaced on a circle around the well could be shot first and additional holes then spotted in the direction of least travel times indicated on the records obtained. A velocity survey of the well should be made, of course, but even with this information it will be difficult to determine the exact profile of the reef surface. A method such as that described by Gardner[10] can be applied but will not be nearly as effective in reef boundary determination as in salt dome delineation.

[10] L. W. Gardner, "Seismograph Determination of Salt Dome Boundary Using Well Detector Deep on Dome Flank," *Geophysics*, XIV, No. 1 (January, 1949), 29–38.

As an alternative to this arrangement, shots can be detonated in the well provided, of course, the well is not a producer. Geophones laid along two lines at right angles across the well would measure the difference in travel times. The well should be shot from the bottom up and after the first shot it would be advisable to rotate the entire spread 45 degrees in order to locate more definitely the highest part of the reef. With the spread showing greatest time differences remaining in position, shots fired at intervals up the well would provide a great deal of data. A geophone placed on the surface at the well would, of course, provide the conventional velocity survey.

REQUIREMENTS FOR AN EFFECTIVE EXPLORATION PROGRAM

An effective exploration program for limestone reef production will require great co-operation between the geologist and geophysicists engaged in the work. Prior to the commencement of geophysical surveys, a thorough study of the paleogeography of the region must be made in order to localize, and thus cover more thoroughly, the areas of greatest potentialities. All data available from known reefs in the area should be examined carefully, especially with respect to any density, velocity and lithologic differences which may exist between the reef and off-reef materials. The results of such an examination will be invaluable as a means of setting up criteria for recognizing reef effects.

All of the various geophysical methods when applied to reef location will require great density of control. Refraction surveys may prove valuable when used in connection with gravity and reflection data.

The success of any geophysical program directed toward reef location will depend more upon the quality of interpretation given the data obtained, than upon any other single factor. The geophysicist engaged in such work will be required to display a great deal of a quality that for want of a better term, we might call "reef-mindedness." The essentials of "reef-mindedness" include a comprehensive knowledge of reefs: what they are; where they are apt to occur; and how they may affect the data obtained by the particular geophysical method being used. It will also include an acute awareness of the almost nebulous nature which will, all too often, be characteristic of the reef indications that will form the only basis of recommendations for additional control.

The problem of locating limestone reefs presents a great challenge to the geophysicist, and its solving will require the application of all the knowledge and ability at his command.

ACKNOWLEDGMENTS

The author wishes to thank all those whose help and criticisms have made this paper possible. Particularly appreciated is the kind permission of The Skelly Oil Company and The Pan American Production Company for use of data on the Eskota Field.

INDUCTIVE COUPLING OF A HOMOGENEOUS GROUND WITH A VERTICAL COIL*

A. BELLUIGI†

ABSTRACT

The problem of the "magnetic pulsating pole" is examined from an analytical viewpoint and an integral solution is reached with the use of Hankel's Integrals. However, a complete explanation was derived only with respect to the horizontal component of the magnetic field. In addition the problem of the "pulsating magnetic dipole" is also explored and similarly a complete explanation is derived only for the horizontal component. The application of the results of these analyses to field prospecting methods is also discussed.

HARMONICALLY VARYING MAGNETIC POLE

Formation of the Problem.—A harmonically varying magnetic pole is placed at a point O of the atmosphere, and the underlying ground is homogeneous and of uniform electrical conductivity, σ. We propose to determine the electromagnetic field which is produced by the harmonically varying pole. Displacement currents are assumed to be negligible. Let O be the origin of the coordinate system, and let the z-axis be vertical and positive downward. Let the surface of the ground be at $z=h$. The electromagnetic field possesses a rotational symmetry about the z-axis. If P is any point in the ground or the atmosphere, and C the circle obtained by the rotation of P around the z-axis, then the electric field $\mathcal{E}$ will obviously be tangential to the circle C and the magnetic field $\mathcal{H}$ will lie in the plane passing through the point P and the z-axis. The sole components not equal to zero of fields $\mathcal{E}$ and $\mathcal{H}$ are therefore:

Horizontal components: $\mathcal{E}_\theta$, tangential component of $\mathcal{E}$;
$\mathcal{H}_\rho$, radial component of $\mathcal{H}$.

Vertical component: $\mathcal{H}_z$.

The amplitude of the harmonically varying pole can be written

$$\mathcal{M} = ReM\epsilon^{i\omega t}$$

where Re indicates "the real part of," ω represents the angular frequency and i represents the operator $\sqrt{-1}$. Likewise for the field components

$$\mathcal{E}_\theta = ReE_\theta\epsilon^{i\omega t}$$

$$\mathcal{H}_\rho = ReH_\rho\epsilon^{i\omega t}$$

$$\mathcal{H}_z = ReH_z\epsilon^{i\omega t}$$

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where E_θ, H_ρ, and H_z are functions of the space coordinates but not of time. The equations pertaining to E_θ, H_ρ and H_z are

$$\text{curl } H = 4\pi\sigma E; \qquad -i\omega H = \text{curl } E \tag{1}$$

from which follows

$$\nabla^2 H + k^2 H = 0$$

where

$$k^2 = 4\pi\sigma\omega i.$$

The second part of equation (1) yields, after transformation to cylindrical coordinates,

$$H_\rho = \frac{1}{i\omega}\frac{\partial E_\theta}{\partial z}; \qquad H_z = -\frac{1}{i\omega}\frac{1}{\rho}\frac{\partial(\rho E_\theta)}{\partial \rho}. \tag{1a}$$

Introduction of the Lipschitz Integral.—The horizontal plane $z=O$, which is the plane passing through the origin of the coordinate system, and the horizontal plane $z=h$ (the surface of the earth) separates space into three zones designated as 0, 1, and 2, with 0 the uppermost zone.

We shall now examine how the radial component H_ρ of the magnetic field behaves in each of these three zones. If the conductivity was everywhere zero, the magnetic field at a point P would be the empty space field produced by a pole M located at the origin

$$H_\rho = -\frac{\partial}{\partial \rho}\frac{M}{r}, \tag{2}$$

where r is the distance between the origin and the point P. We can express the term $1/r$ by the Lipschitz integral

$$\text{for } z < 0: \quad \frac{1}{r} = \int_0^\infty \epsilon^{\lambda z} J_0(\lambda\rho)\, d\lambda;$$

$$\text{for } z > 0: \quad \frac{1}{r} = \int_0^\infty \epsilon^{-\lambda z} J_0(\lambda\rho)\, d\lambda;$$

where $r=(z^2+\rho^2)^{1/2}$. Equation (2) becomes

$$\text{for } z < 0: \quad H_\rho = M\int_0^\infty \lambda\epsilon^{\lambda z} J_1(\lambda\rho)\, d\lambda;$$

$$\text{for } z > 0: \quad H_\rho = M\int^\infty \lambda\epsilon^{-\lambda z} J_1(\lambda\rho)\, d\lambda;$$

where $J_n(\lambda\rho)$ is Bessel's function of the first kind and order n. However, since

the conductivity of the ground is not zero, there is a contribution to the field at point P due to the currents induced in the ground. This contribution can be expressed by an equation of the following type:

$$\text{for} \quad z < h: \quad H_\rho = M \int_0^\infty a\epsilon^{\lambda z} J_1(\lambda\rho)d\lambda;$$

where a is a function of λ to be determined by the boundary conditions. The total field existing in zones 0 and 1 will therefore be

$$H_{0\rho} = M \int_0^\infty (\lambda + a)\epsilon^{\lambda z} J_1(\lambda\rho)d\lambda; \tag{3}$$

$$H_{1\rho} = M \int_0^\infty (\lambda\epsilon^{-\lambda z} + a\epsilon^{\lambda z}) J_1(\lambda\rho)d\lambda. \tag{4}$$

In zone 2 we will have

$$H_{2\rho} = M \int_0^\infty b\epsilon^{-Rz} J_1(\lambda\rho)d\lambda \tag{5}$$

where $R^2=\lambda^2-k^2$ and b is a function of λ to be determined by the boundary conditions.

We now examine the vertical component H_z: from equation (1a) the expressions for E_θ are obtained by multiplying equations (3), (4), and (5) by $i\omega$ and integrating the products with respect to z:

$$E_{0\theta} = i\omega M \int_0^\infty \left(1 + \frac{a}{\lambda}\right)\epsilon^{\lambda z} J_1(\lambda\rho)d\lambda;$$

$$E_{1\theta} = i\omega M \int_0^\infty \left(-\epsilon^{-\lambda z} + \frac{a}{\lambda}\epsilon^{\lambda z}\right) J_1(\lambda\rho)d\lambda;$$

$$E_{2\theta} = i\omega M \int_0^\infty \frac{b}{R} - \epsilon^{-Rz} J_1(\lambda\rho)d\lambda.$$

It then follows that

$$H_{0z} = -M \int_0^\infty (\lambda + a)\epsilon^{\lambda z} J_0(\lambda\rho)d\lambda;$$

$$H_{1z} = -M \int_0^\infty (-\lambda\epsilon^{-\lambda z} + a\epsilon^{\lambda z}) J_0(\lambda\rho)d\lambda;$$

$$H_{2z} = -M \int_0^\infty -\frac{b\lambda}{R}\epsilon^{-Rz} J_0(\lambda\rho)d\lambda.$$

Boundary Conditions.—If the magnetic susceptibility is everywhere equal

to unity, the conditions that $H_{1\rho}=H_{2\rho}$ and $H_{1z}=H_{2z}$ at the surface of the ground gives

$$\lambda\epsilon^{-\lambda h}+a\epsilon^{\lambda h}=b\epsilon^{-Rh};$$

$$-\lambda\epsilon^{-\lambda h}+a\epsilon^{\lambda h}=-\frac{b\lambda}{R}\epsilon^{-Rh};$$

from which

$$a=\frac{(R-\lambda)\lambda}{R+\lambda}\epsilon^{-2\lambda h};$$

$$b=\frac{2\lambda R}{R+\lambda}\epsilon^{(R-\lambda)h};$$

and we can write, for points at the surface of the ground,

$$H_\rho=M\int_0^\infty\frac{2\lambda R}{R+\lambda}\epsilon^{-\lambda h}J_1(\lambda\rho)d\lambda;$$

$$H_z=M\int_0^\infty\frac{2\lambda^2}{R+\lambda}\epsilon^{-\lambda h}J_0(\lambda\rho)d\lambda.$$

Computable Expression for H_ρ.—Upon multiplying both the numerator and denominator of the integrand of the preceding expression for H_ρ by $(\lambda-R)$, and keeping in mind the identity $\lambda^2-R^2=k^2$, we obtain

$$H_\rho=\frac{2M}{k^2}\int_0^\infty(\lambda^2R-\lambda^3+\lambda k^2)\epsilon^{-\lambda h}J_1(\lambda\rho)d\lambda. \tag{6}$$

In order to evaluate this, we first use Sommerfeld's integral

$$\int_0^\infty\frac{\lambda}{R}\epsilon^{-Rz}J_0(\lambda\rho)d\lambda=\frac{1}{r}\epsilon^{ikr}.$$

Taking the derivatives of this integral once with respect to ρ and then twice with respect to z

$$\int_0^\infty\lambda^2R\epsilon^{-Rz}J_1(\lambda\rho)d\lambda=-\frac{\partial^3}{\partial^2z\partial\rho}\left(\frac{1}{r}\epsilon^{ikr}\right). \tag{7}$$

Next we make use of the Lipschitz integral for $z>0$

$$\int_0^\infty\epsilon^{-\lambda z}J_0(\lambda\rho)d\lambda=\frac{1}{r}.$$

Taking the derivatives with respect to ρ, we obtain

$$\int_0^\infty \lambda \epsilon^{-\lambda z} J_1(\lambda\rho) d\lambda = -\frac{\partial}{\partial\rho}\left(\frac{1}{r}\right). \tag{8}$$

Taking the derivative of equation (8) twice with respect to z, we obtain

$$\int_0^\infty \lambda^3 \epsilon^{-\lambda z} J_1(\lambda\rho) d\lambda = -\frac{\partial^3}{\partial z^2 \partial\rho}\left(\frac{1}{r}\right). \tag{9}$$

Set $z=h$ in equations (7), (8), and (9) and substitute into equation (6):

$$H_\rho = \frac{2M}{k^2}\left[-\frac{\partial^3}{\partial z^2\partial\rho}\left(\frac{1}{r}\,\epsilon^{ikr}\right) + \frac{\partial^3}{\partial z^2\partial\rho}\left(\frac{1}{r}\right) - k^2\frac{\partial}{\partial\rho}\left(\frac{1}{r}\right)\right]. \tag{10}$$

For the particular case of the harmonically varying pole located at the surface of the ground, upon performing the operations indicated in equation (10) and then setting $h=0$, there results

$$H_\rho = \frac{2M}{k^2\rho^4}\left[(k^2\rho^2 + 3ik\rho - 3)\epsilon^{ik\rho} + k^2\rho^2 + 3\right]. \tag{11}$$

If we define γ_1 as the ratio between the field given above and the stationary field M/ρ^2 which would have resulted from a non-varying pole of strength M

$$\gamma_1 = \frac{2}{k^2\rho^2}\left[(k^2\rho^2 + 3ik\rho - 3)\epsilon^{ik\rho} + k^2\rho^2 + 3\right] = \alpha_1 + i\beta_1$$

where

$$\alpha_1 = 2 + \frac{\epsilon^{-n}}{n^2}\left[(2n^2 + 3n)\cos n - (3 + 3n)\sin n\right];$$

$$\beta_1 = \frac{1}{n^2}\left[-3 + \epsilon^{-n}\{(3 + 3n)\cos n + (2n^2 + 3n)\sin n\}\right]$$

and $n=\rho(2\pi\sigma\omega)^{1/2}$ is a numerical distance. At large numerical distances, the ratio approaches the value 2.

We believe that it is not possible to express the complete field by an elementary formula as has been done for H_ρ at the surface of the ground.

CIRCULAR COIL IN A VERTICAL PLANE

We will assume that a single turn coil of radius R_1, through which an alternating current flows, is situated on the surface of a homogeneous and isotropic ground with the plane of the coil vertical and the center of the coil at or near the surface of the ground. We wish to determine the horizontal electromagnetic field produced over the ground surface.

Let the origin of the coordinate system be at the geometrical center of the coil with the z-axis vertical and positive downwards and the x-axis perpendicular

to the plane of the coil. The positive direction of the z-axis is given by the direction of ths magnetic field produced by a positive current in the coil. The current in the coil is ReI where $I=i_0\epsilon^{i\omega t}$.

The magnetic effect of the current flowing in the coil is equivalent to that of a plane magnetic shell of infinitesimal thickness α whose boundary conicides with the conducting wire, and whose magnetic moment is $\pi R_1^2 I$. At distances large compared with R_1, the effect of the equivalent shell is the same as that of a small bar magnet of pole strength $\pi R_1^2 I/\alpha$. Consider the pole $\pi R_1^2 I/\alpha$ located at the origin and the pole $-(\pi R_1^2 I/\alpha)$ located on the x-axis at $x=-\alpha$. If $H(x, y, o)$ is the vector field produced at a point $P\ (x, y, o)$ by a harmonically varying pole located at the origin, the pole having unit pole strength, then the field due to the pair of poles just described is

$$-\frac{\pi R_1^2 I}{\alpha}\left\{H(x+\alpha, y, o) - H(x, y, o)\right\},$$

which in the limit as $\alpha\to\infty$ becomes

$$F = -\pi R_1^2 I \frac{\partial H}{\partial x},$$

a vector equation whose rectangular components are

$$F_x = -\pi R_1^2 I \frac{\partial H_x}{\partial x} = -\pi R_1^2 I \frac{\partial}{\partial x}\left(\frac{x}{\rho} H_\rho\right) = -\pi R_1^2 I\left(\frac{x^2}{\rho^2}\frac{\partial H_\rho}{\partial \rho} + \frac{y^2}{\rho^3} H_\rho\right);$$

$$F_y = -\pi R_1^2 I \frac{\partial H_y}{\partial x} = -\pi R_1^2 I \frac{\partial}{\partial x}\left(\frac{y}{\rho} H_\rho\right) = -\pi R_1^2 I\left(\frac{xy}{\rho^2}\frac{\partial H_\rho}{\partial \rho} - \frac{xy}{\rho^3} H_\rho\right).$$

The radial and tangential components of the field are

$$F_\rho = F_x\frac{x}{\rho} + Fy\frac{y}{\rho} = -\pi R_1^2 I\frac{x}{\rho}\frac{\partial H_\rho}{\partial \rho}; \tag{12}$$

$$F_\theta = F_x\frac{y}{\rho} - Fy\frac{x}{\rho} = -\pi R_1^2 I\frac{y}{\rho^2} H_\rho; \tag{12a}$$

where

$$H_\rho = \frac{2}{k^2\rho^4}\left[(k^2\rho^2 + 3ik\rho - 3)\epsilon^{ik\rho} + k^2\rho^2 + 3\right];$$

$$\frac{\partial H_\rho}{\partial \rho} = \frac{2}{k^2\rho^5}\left[(ik^3\rho^3 - 5k^2\rho^2 - 12ik\rho + 12)\epsilon^{ik\rho} - 2k^2\rho^2 - 12\right].$$

Had the current in the coil been direct current instead of sinusoidal, the stationary field resulting would have been

$$F_\rho' = \pi R_1^2 I\frac{2x}{\rho^4}.$$

$$F_\theta' = -\pi R_1^2 I \frac{y}{\rho^4},$$

and the ratios of the fields for the two conditions are

$$\gamma_2 = \frac{F_\rho}{F_\rho'} = -\frac{1}{k^2\rho^2}\left[(ik^3\rho^3 - 5k^2\rho^2 - 12ik\rho + 12)\epsilon^{ik\rho} - 2k^2\rho^2 - 12\right]$$
$$= \alpha_2 + i\beta_2;$$

$$\gamma_2' = \frac{F_t}{F_t'} = \frac{2}{k^2\rho^2}\left[(k^2\rho^2 + 3ik\rho - 3)\epsilon^{ik\rho} + k^2\rho^2 + 3\right] = \gamma_1 = \alpha_1 + i\beta_1;$$

where

$$\alpha_2 = -2 + \frac{\epsilon^{-n}}{n^2}\left[(6n + 5n^2 + n^3)\cos n + (-6 - 6n + n^3)\sin n\right];$$

$$\beta_2 = \frac{6}{n^2} + \frac{\epsilon^{-n}}{n^2}\left[(6 + 6n - n^3)\cos n + (6n + 5n^2 + n^3)\sin n\right].$$

The essential results of this analysis for a homogeneous earth are as follows:

(1) For a harmonically varying pole situated at the ground surface and of peak pole strength M, the radial component of the resulting magnetic field at the surface of the ground is

$$H_\rho = \frac{M}{\rho^2}(\alpha_1 + i\beta_1).$$

The ratio at any point of H_ρ to the stationary field which would have been caused by a pole of constant pole strength M is $(\alpha_1+i\beta_1)$ which, for large distances from the pole, approaches the value 2.

(2) For a coil of radius R_1 carrying an alternating current of peak amplitude I, the coil placed so that its plane is vertical and its center at the ground level, the radial and tangential components of the resulting magnetic field along the surface are

$$F_\rho = \pi R_1^2 I \frac{2x}{\rho^4}(\alpha_2 + i\beta_2);$$

$$F_\theta = -\pi R_1^2 I \frac{y}{\rho^4}(\alpha_1 + i\beta_1).$$

The ratios at any point of F_ρ and F_θ to the radial component and the tangential component, respectively, which would have been caused by allowing a direct current of I amperes to flow through the coil are $(\alpha_2+i\beta_2)$ and $\alpha_1+i\beta_1)$. For large distances from the coil, the ratio of the radial components approaches the value 2 and is oppositely directed; for the tangential components at large distances, the ratio approaches the value 2.

THE COMPUTATION OF SECOND VERTICAL DERIVATIVES OF GEOMAGNETIC FIELDS*

ROLAND G. HENDERSON† AND ISIDORE ZIETZ†

ABSTRACT

Second vertical derivatives of magnetic fields, because of their high resolving power, are often very useful in interpreting magnetic anomalies. Formulas are developed which permit their ready numerical computation. Comparisons are made between the resulting approximate values and the rigorous values obtained for simple idealized fields. The similarity between maps of second vertical derivatives of fields and those of certain types of residual fields is discussed.

INTRODUCTION

The airborne magnetometer, as employed in mapping geomagnetic anomalies, has been in extensive use by the U. S. Geological Survey for about 5 years. The quantitative use of magnetics is limited because of the low resolving power of the method and because of the ambiguity in magnetic interpretations. Despite these limitations, there is justification for getting as much out of the data as possible. An advantage of the method is its use in preliminary surveys to disclose areas in which geophysical methods of higher resolving power may be used.

Qualitative and quantitative interpretations can be made more objective by constructing second vertical derivative maps or so-called residual maps of the observed field. H. M. Evjen[1] demonstrated the higher resolving power of the first vertical derivative of the two-dimensional gravitational anomaly field produced by two parallel line sources. Even greater resolution is afforded by the second vertical derivatives of the field. In a forthcoming publication, V. Vacquier suggests the use of second derivatives in conjunction with prismatic models to estimate depths to the basement from total magnetic intensity anomalies.

Second vertical derivative maps have been computed for aeromagnetic surveys over regions where the geology was fairly well known. The interesting feature about such maps is the manner in which they tend to delineate geologic formations known to be magnetic. Also, the presence of magnetic rocks in sediments is disclosed more prominently than is possible with the observed field. Second vertical derivatives also are useful in the analytical continuation of magnetic fields towards sources, although such uses are limited by the accuracy both of the data and of the method of computing.

The recognized importance of these derivatives led the authors to study the means by which they may be computed. The accuracy and limitations of the approximation formulas developed herein are examined in relation to rigorous values obtained from elementary fields.

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[1] H. M. Evjen, "The Place of the Vertical Gradient in Gravitational Interpretations," *Geophysics*, Vol. I, No. 1, January, 1936.

MATHEMATICAL THEORY

If ΔV is the anomaly in magnetic potential, at all points of free space it satisfies the Laplace equation

$$\nabla^2(\Delta V) = 0 \tag{1}$$

The component of the total-intensity anomaly, ΔT, in the direction of the earth's normal field (assumed invariant over the area) is given by

$$\Delta T = -\frac{\partial(\Delta V)}{\partial t} \tag{2}$$

where $\overrightarrow{t}$ is the unit vector in the direction of the earth's undisturbed field. The equation (2) is valid as long as $\Delta T \ll T_0$ where T_0 is the magnitude of the total field. Operating on each side of equation (2) with

$$\nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2},$$

in consequence of equation (1) there results

$$\nabla^2(\Delta T) = \frac{\partial^2(\Delta T)}{\partial x^2} + \frac{\partial^2(\Delta T)}{\partial y^2} + \frac{\partial^2(\Delta T)}{\partial z^2} = 0. \tag{3}$$

Therefore ΔT, on the bases assumed, satisfies the Laplace equation and admits of analysis by the methods of potential theory.

$\Delta T(x, y, 0)$ is known at most at an infinite number of points on a finite number of flight lines spaced generally from one-quarter mile to 1 mile apart. After preparation of a magnetic-contour map, the anomaly is known approximately over the plane of observations. The second vertical derivative at a point may be computed with the aid of a function which satisfies equation (3), vanishes at infinity, and reduces approximately to the contoured values of ΔT on the plane of observations.

Suppose a right-handed system of coordinates is adopted in which the origin is taken at the center of the anomaly and the z-axis is taken positive vertically upward. A satisfactory solution to equation (3) in terms of a Fourier-Bessel expansion is

$$\Delta T(z, r, \phi) = \sum_{k=1}^{K} \sum_{n=0}^{N} e^{-\mu_k z}[A_{kn} \cos n\phi + B_{kn} \sin n\phi] J_n(\mu_k r) \tag{4}$$

where $x = r \cos \phi$, $y = r \sin \alpha$, k and n are positive integers A_{kn} and B_{kn} are constants to be determined; $J_n(\mu_k r)$ is a Bessel function of the first kind, and μ_k are positive roots of $J_n(\mu_k a) = 0$ where a is a large value of the radius, r at which the anomaly ΔT is effectively zero, or has been arbitrarily made so.

Differentiating equation (4) and allowing z to approach zero we have

$$\frac{\partial^2 \Delta T}{\partial z^2} = \sum_{k=1}^{K} \sum_{n=0}^{N} \mu_k^2 [A_{kn} \cos n\phi + B_{kn} \sin n\phi] J_n(\mu_k r) \tag{5}$$

The constants A_{kn}, B_{kn} of equation (5) can be obtained from equation (4) when $z=0$; however, the computation is time consuming and laborious. Equation (4) is greatly simplified when dependence on ϕ is eliminated. This can be effected approximately in the following manner: A square grid is superimposed and the value of ΔT interpolated at each grid corner (see Fig. 1). On the first circle, radius unity, about the origin there are the four values ΔT_{11}, ΔT_{12}, ΔT_{13}, ΔT_{14}; on the sec-

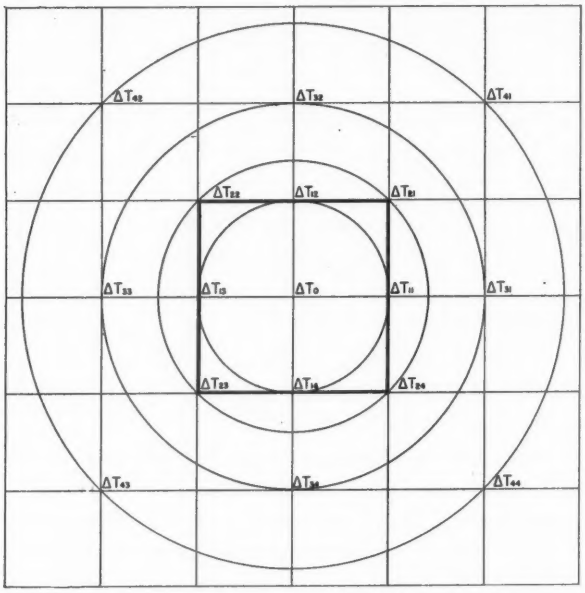

FIG. 1. Values of $\Delta T(r)$ for determining $\overline{\Delta T}$.

ond circle, radius $\sqrt{2}$, there are the four values ΔT_{21}, ΔT_{22}, ΔT_{23}, ΔT_{24} and on the jth circle the values ΔT_{j1}, ΔT_{j2}, ΔT_{j3}, ΔT_{j4}. By taking the average value of ΔT on each circle it can be easily shown that dependence on ϕ is eliminated and as a consequence only Bessel functions of zero order, i.e., $J_0(\mu_k r)$, remain in the expansion (4). It has been assumed that four points are adequate for representing the average value of ΔT on each circle. With these modifications we have

$$\overline{\Delta T}(r) = \sum_{k=1}^{K} A_k J_0(\mu_k r) \tag{6}$$

where $A_{k0} \equiv A_k$, and $\overline{\Delta T}$ represents the average value of ΔT on the circle of radius r. Equation (4) can now be written

$$\Delta T(z, r) = \sum_{k=1}^{K} A_k e^{-\mu_k z} J_0(\mu_k r) \tag{7}$$

where

$$\Delta T(0, r)^t \equiv \overline{\Delta T}(r).$$

From equation (7) the required derivative at the origin is

$$\frac{\partial^2 \Delta T}{\partial z^2} = \sum_{k=1}^{K} \mu_k^2 A_k J_0(\mu_k 0) = \sum_{k=1}^{K} \mu_k^2 A_k. \tag{8}$$

Equation (8) affords a means of computing the second vertical derivative of ΔT at the origin. The coefficients A_k can be evaluated by solving k equations in k unknowns involving the value of the anomaly at the center and the average values of ΔT on $k-1$ circles about the origin.

There is no loss in generality if the origin is taken at the point where $\partial^2 \Delta T/\partial z^2$ is desired. There is wide latitude in the choice of $r=a$, the value where ΔT is essentially zero, as we are concerned with fitting values of ΔT in the neighborhood of the origin. Usually $\overline{\Delta T}$ on two or three circles about the origin yields values of sufficient accuracy.

To put equation (8) into a form more convenient for computation, let ΔT_0 be the value of the field at the point where the derivative is sought, and $\overline{\Delta T_1}$ $\overline{\Delta T_2}$ the average values of the field on circles of radii r_1 and r_2 respectively. Then from equation (6)

$$\begin{aligned} \Delta T_0 &= A_1 + A_2 + A_3 \\ \overline{\Delta T}_1 &= A_1 J_0(\mu_1 r_1) + A_2 J_0(\mu_2 r_1) + A_3 J_0(\mu_3 r_1) \\ \overline{\Delta T}_2 &= A_1 J_0(\mu_1 r_2) + A_2 J_0(\mu_2 r_2) + A_3 J_0(\mu_3 r_2). \end{aligned} \tag{9}$$

In solving for the coefficients A_1, A_2, A_3 in equations (9) it is convenient to use a nine-point system consisting of ΔT_0 and eight neighboring points. Then $r_1=1$, $r_2=\sqrt{2}$ as shown in Figure 1. Suppose we take $a=10$ as the radius at which the idealized anomaly is arbitrarily smoothed to zero. Then from $J_0(\mu_k 10)=0$ we have[2] $\mu_1=0.2405$, $\mu_2=0.5520$, $\mu_3=0.8654$ and

$$\begin{aligned} J_0(\mu_1 r_1) &= 0.9856 & J_0(\mu_2 r_1) &= 0.9253 & J_0(\mu_3 r_1) &= 0.8215 \\ J_0(\mu_1 r_2) &= 0.9713 & J_0(\mu_2 r_2) &= 0.8534 & J_0(\mu_3 r_2) &= 0.6592 \end{aligned}$$

Inserting these values in (9), A_1, A_2, A_3 are determined. Equation (8) then becomes

$$\frac{\partial^2 \Delta T}{\partial z^2} = 6.185 \Delta T_0 - 8.374 \overline{\Delta T}_1 + 2.189 \overline{\Delta T}_2 \tag{10}$$

which is a working formula for computing the indicated curvature.

By expanding $J_0(\mu_k r)$ in equation (6) in its defining power series a second and simpler expression for $\partial^2 \Delta T/\partial z^2$ is possible.

$$\overline{\Delta T}(r) = \sum_{k=1}^{K} A_k J_0(\mu_k r) = \sum_{k=1}^{K} A_k - \frac{r^2}{4} \sum_{k=1}^{K} \mu_k^2 A_k + \frac{r^4}{64} \sum_{k=1}^{K} \mu_k^4 A_k + \cdots. \tag{11}$$

[2] E. Jahnke and F. Emde, "Tables of Functions" *Dover Publications*, 1945.

In consequence of equation (6) and equation (8), equation (11) may be written

$$\overline{\Delta T}(r) = \Delta T_0 - \frac{r^2}{4}\frac{\partial^2 \Delta T}{\partial z^2} + \frac{r^4}{64}\sum \mu_k^4 A_k + \cdots . \tag{12}$$

Using a nine-point system with $r=1$ and $r=\sqrt{2}$ in equation (12) we have two simultaneous equations from which $\partial^2\Delta T/\partial z^2$ can be obtained. The solution is:

$$\frac{\partial^2 \Delta T}{\partial z^2} = 2(3\Delta T_0 - 4\overline{\Delta T}_1 + \Delta T_2). \tag{13}$$

APPLICATIONS OF THE SECOND VERTICAL DERIVATIVE FORMULAS

Either formula may be applied to determine the derivatives on the plane of observation. In practice, however, the use of equation (13) greatly simplifies the calculations, the values differing negligibly from those obtained by using equation (10).

To investigate the accuracy of the methods, a theoretical anomaly, ΔT, due to a point pole in a magnetic field of inclination 90° has been computed for depths of 2.5, 5.0, and 10.0 units respectively. A check on the accuracy of the process is provided since the formula for the rigorous computation of $\partial^2\Delta T/\partial z^2$ is obtained by differentiating the mathematical expression[3] for ΔT. The formula is

$$\frac{\partial^2 \Delta T}{\partial z^2} = -\frac{15m\zeta^3}{(x^2+y^2+\zeta^2)^{7/2}} + \frac{9m\zeta}{(x^2+y^2+\zeta^2)^{5/2}} \tag{14}$$

where x, y, o are the coordinates of the point at which ΔT is evaluated and o, o, ζ are the coordinates of the point pole of strength m. Computations using the various methods are tabulated and presented in Table 1 for $m=1000$. For a grid of one-half unit spacings, the formulas are modified by multiplying the right-hand members by four.

It should be observed that for decreasing depths, the horizontal gradient and curvature of the ΔT anomaly increase and the agreement between true and computed values becomes less favorable. When $\zeta=2.5$ and the grid spacing is unity, satisfactory checks are no longer obtained. The situation is remedied by reducing the grid spacing by one half. As a result, the determinations obtained from the formulas agree with the true value for the derivative. By including a third circle, slightly different values are obtained. The formula is derived by inserting into equation (12) the average values ΔT_0, $\overline{\Delta T}_1$, $\overline{\Delta T}_2$, $\overline{\Delta T}_3$ on circles of radii 0, 1, $\sqrt{2}$, 2 units respectively. This leads to three simultaneous equations which are easily evaluated. The solution is:

$$\frac{\partial^2 \Delta T}{\partial z^2} = \frac{21\Delta T_0 - 32\Delta T_1 + 12\Delta T_2 - \Delta T_3}{3}. \tag{15}$$

[3] R. G. Henderson and I. Zietz, "Analysis of total magnetic-intensity anomalies produced by point and line sources." *Geophysics*, 13, No. 3 (1948) 428–436.

TABLE 1

COMPARISONS OF VALUES OF $1/4\frac{\partial^2 \Delta T}{\partial z^2}$ COMPUTED FROM DERIVED FORMULAS.

FIELD IS THAT OF A POINT POLE AT VARIOUS DEPTHS.

Depth, $\zeta = 10$

x	y	True Value $\frac{1}{4}\frac{\partial^2 \Delta T}{\partial z^2}$	Unit Grid Spacing Values by Formula I	II	III
0	0	0.15	0.15	0.16	0.16
2	1	0.11	0.10	0.10	0.10
2	3	0.07	0.06	0.06	0.06
3	3	0.06	0.06	0.06	0.06

Depth, $\zeta = 5$

x	y	True Value $\frac{1}{4}\frac{\partial \Delta^2 T}{\partial z^2}$	Unit Grid Spacing Values by Formula I	II	III
0	0	2.40	2.41	2.36	2.41
1	1	1.61	1.62	1.61	1.63
2	2	0.47	0.52	0.51	0.53
2	3	0.12	0.12	0.12	0.15

Depth, $\zeta = 2.5$

x	y	True Value $\frac{1}{4}\frac{\partial^2 \Delta T}{\partial z^2}$	Unit Grid Spacing Values by Formula I	II	III	0.5 Unit Grid Spacing Values by Formula I	II	III	0.25 Unit Grid Spacing Values by Formula I	II	III
0	0	38.40	37.02	36.61	37.63	38.36	38.24	38.38	38.40	38.40	38.33
1	1	7.56	8.81	8.78	9.26	7.94	7.94	8.26	7.76	7.76	7.88
2	0	0.27	−1.25	−1.10	−0.58	−0.27	−0.22	−0.67	0.23	0.24	0.16
2	2	−1.98	−0.73	−0.79	0.28	−1.68	−1.70	−1.37	−1.96	−1.96	−1.86
3	1	−1.90	−2.21	−2.18	−2.42	−2.03	−2.02	−2.10	−1.92	−1.92	−1.94

When a half-unit grid is used, the right-hand member is multiplied by four. Referring to Table 1, it is evident that the addition of a third circle does not significantly increase the accuracy of the derivative.

Generally, the finer the grid spacing, the better the fit and the more accurate is the computed value of the second derivative as was shown for the point pole. However, in certain types of exploration the local or shallow anomalies are of little or no interest because of their industrial or sedimentary character, and theoretically should be removed before the derivatives are calculated. Practically the latter can be effected by increasing the grid spacing to a size commensurate with the magnetic features to be studied.

As an illustration of the effect of grid size consider the aeromagnetic map of the Clearfield-Philipsburg area in central Pennsylvania in Figure 2. The second derivative of this field computed on a 1-mile grid is shown in Figure 3. This map is characterized by numerous foci, some of which are doubtless due to industrial installations and to near-surface magnetic material. The closed high in the lower right-hand corner occurs over Pennsylvania State College. The second derivative map, Figure 4, of the same area is computed on a 3-mile grid. These anomalies are broader and are probably associated with deep magnetic features. A very similar second derivative map (not shown here) was obtained for a grid of 2 miles.

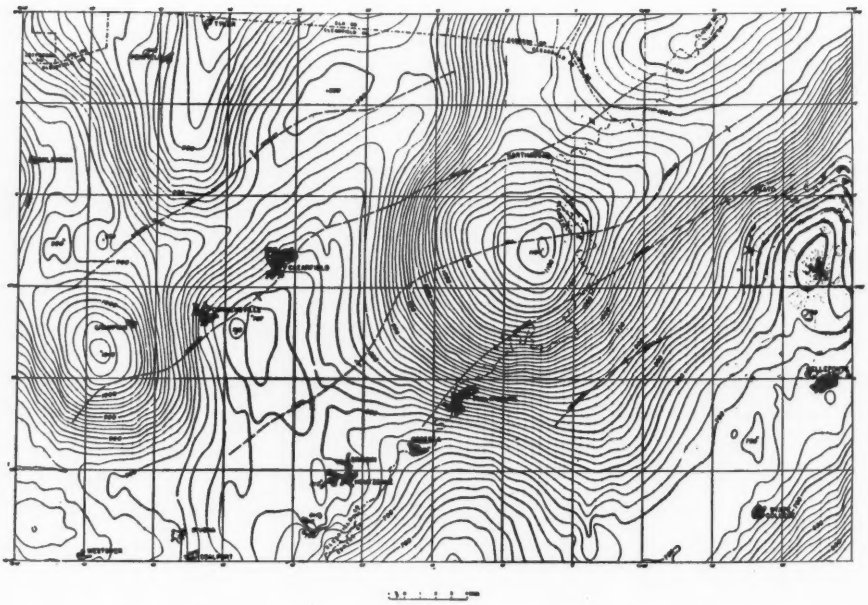

FIG. 2. Aeromagnetic map of Clearfield-Philipsburg Area, Pennsylvania, showing variation in total intensity. Contour interval 10 gammas. Flown approximately 10,000 feet above the surface.

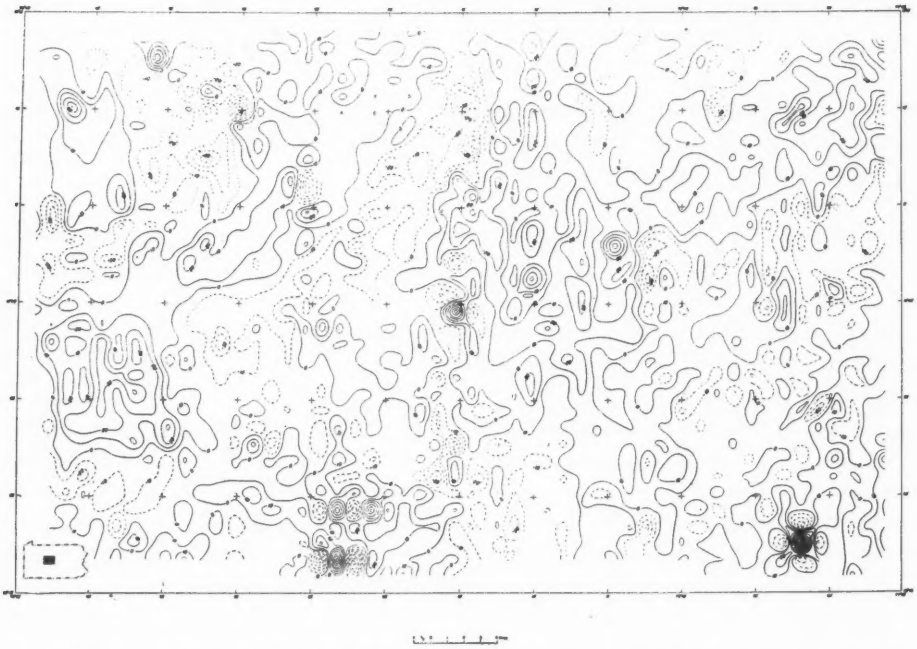

FIG. 3. Aeromagnetic map of Clearfield-Philipsburg Area, Pennsylvania, showing second vertical derivatives of total magnetic intensity computed on one-mile grid. Contour interval 10 gammas per mile squared. Flown approximately 1,000 feet above the surface.

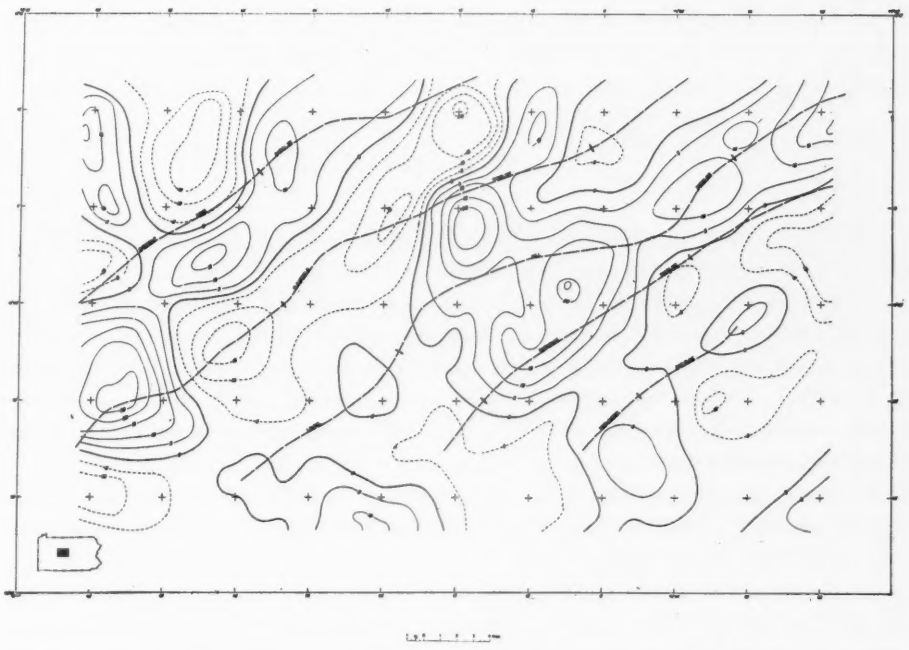

FIG. 4. Aeromagnetic map of Clearfield-Philipsburg Area, Pennsylvania, showing second vertical derivatives of total magnetic intensity computed on 3-mile grid. Contour interval 5 gammas per mile squared. Flown approximately 1,000 feet above the surface.

RELATIONSHIP BETWEEN THE SECOND VERTICAL DERIVATIVE AND RESIDUAL MAPS

It has already been established that in the neighborhood of the point the anomaly may be represented by a power series of the form

$$\overline{\Delta T}(r) = \sum_{k=1}^{K} A_k - \frac{r^2}{4} \sum_{k=1}^{K} A_k \mu_k^2 + \frac{r^4}{64} \sum_{k=1}^{K} A_k \mu_k^4 + \cdots$$

(see equation (11)) where $\overline{\Delta T}(r)$ is the average value of the field at a distance r from the point at which the second vertical derivative is to be evaluated. Neglecting terms of the fourth order and higher, equation (11) reduces to

$$\overline{\Delta T}(r) = \Delta T_0 - \frac{r^2}{4} \frac{\partial^2 \Delta T}{\partial z^2}. \tag{16}$$

The average values of the field at a distance of one and the $\sqrt{2}$ units respectively from the origin become

$$\overline{\Delta T}_1 = \Delta T_0 - 1/4 \frac{\partial^2 \Delta T}{\partial z^2}$$

$$\overline{\Delta T}_2 = \Delta T_0 - 1/2 \frac{\partial^2 \Delta T}{\partial z^2}. \tag{17}$$

These equations imply that the solutions for $\partial^2\Delta T/\partial z^2$ are numerous, as the computation involves the solution of two linear equations with only one unknown. Multiplying the first of equations (17) by 4 and the second by 1 yields formula

$$\frac{\partial^2\Delta T}{\partial z^2} = 2(3\Delta T_0 - 4\overline{\Delta T}_1 + \overline{\Delta T}_2). \tag{18}$$

Similarly other expressions for $\partial^2\Delta T/\partial z^2$ may be found provided r in $\overline{\Delta T}(r)$ is chosen in the neighborhood of the point.

Of particular interest is the similarity between second vertical derivative and residual maps. Residual maps have been used extensively by geophysicists to bring into focus local features which tend to be obscured by the broad features of the field. Various methods have been recommended for obtaining residual fields. One well-known procedure consists of averaging the field values in the neighborhood of a point and subtracting this average from the value at the point. If the averaging process employs a nine-point system as was used in the computations above, a definite relationship can be shown to exist between the residual and second derivative maps.

Consider the outlined square consisting of four unit squares as shown in Figure 1. The average of the nine grid corner values subtracted from the value at the center gives the residual value at the center. In this case the residual, R, at ΔT_0 becomes

$$R = \Delta T_0 - 1/9(\Delta T_0 + \Delta T_{11} + \Delta T_{12} + \Delta T_{13} + \Delta T_{14} + \Delta T_{21} + \Delta T_{22} + \Delta T_{23} + \Delta T_{24}) \tag{18}$$

or

$$R = 1/9(8\Delta T_0 - 4\overline{\Delta T}_1 - 4\overline{\Delta T}_2). \tag{19}$$

Multiplying both equations in (17) by four and adding, we have

$$\frac{\partial^2\Delta T}{\partial z^2} = 1/3(8\Delta T_0 - 4\overline{\Delta T}_1 - 4\Delta T_2) \tag{20}$$

Consequently,

$$\frac{\partial^2\Delta T}{\partial z^2} = 3R. \tag{21}$$

The units for the second vertical derivative are gammas per unit length squared and those for the residual are gammas. The numerical constant, 3, must therefore contain the dimensions of the reciprocal of length squared.

It follows from equation (21) that the derivative and residual maps of the same area differ only in the magnitude of the horizontal gradient. The location of the maximum, as well as the minimum and zero contours will appear in exactly the same positions.

THE UPWARD CONTINUATION OF ANOMALIES IN TOTAL MAGNETIC INTENSITY FIELDS*

ROLAND G. HENDERSON† AND ISIDORE ZIETZ†

ABSTRACT

In airborne magnetometry consideration must be given to the necessity of multi-level observations. The problem of computing total intensity anomalies from data observed on lower levels is investigated in the case of contours exhibiting both two- and three-dimensional features. It is found that even fairly complex anomalies can be extended, with results differing but slightly from observations at the higher level. Maps for comparing computed and observed anomalies are presented. The mathematical basis is given together with numerical formulas and procedures for affecting the computations.

INTRODUCTION

The advent of the airborne magnetometer, which makes it possible to obtain magnetic data on one or more flight levels in a relatively short time, has revived discussions on the value of multi-level observations. Most geophysicists agree that it is theoretically possible to continue fields in regions devoid of sources; however, many question its practicality when applied to observational data because of the inaccuracy in or the scarcity of the latter, or because of the difficulties inherent in representing it mathematically. Heretofore investigations of the field-extension problem necessarily were confined to distributions computed from simple geometries. Recently aeromagnetic surveys of several areas have provided data on two or more levels above the ground, making possible experimental checks of computations to higher levels.

It is the purpose of this paper to investigate the means, accuracy and limitations of the analytical continuation process in application to aeromagnetic data. Anomalies representing extremes in gradient and irregularity were selected for extension. The results are presented in the form of contour maps which can be readily compared with contour maps of observed data on corresponding levels. Both three-dimensional and two-dimensional fields are treated.

MATHEMATICAL DEVELOPMENT

The flux-gate type magnetometer used in aerial surveys measures ΔT, the component of the total-intensity anomaly in the direction of the total field. This study is confined to ΔT anomalies usually encountered in prospecting, i.e., those covering an area sufficiently small to permit considerations of both a plane earth and an invariant normal field $\overrightarrow{T}$; and those with sufficiently small amplitude to permit the adoption of the direction of $\overrightarrow{T}$ as that of $\overrightarrow{\Delta T}$. Under these conditions ΔT may be regarded as a potential as is shown below.

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Suppose ΔV is the magnetic potential anomaly produced by the disturbing geological formation. At all points of free space ΔV satisfies the Laplace equation

$$\nabla^2(\Delta V) = 0 \tag{1}$$

where

$$\nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}.$$

The component of the total-intensity anomaly in the direction of the earth's normal field is given by

$$\Delta T = -\frac{\partial(\Delta V)}{\partial t} \tag{2}$$

where $\vec{t}$ is the unit vector in the direction of $\vec{T}$. Operating on each side of equation (2) with ∇^2 there results

$$\nabla^2(\Delta T) = -\nabla^2 \frac{\partial(\Delta V)}{\partial t} = -\frac{\partial}{\partial t}\nabla^2(\Delta V) = 0. \tag{3}$$

The interchange of the order of differentiation is permissible since ΔV and its derivatives are continuous. Thus it is established that ΔT satisfies the Laplace equation and is, therefore, amenable to the methods of potential theory.

Suppose we have an aeromagnetic map of ΔT $(x, y,)$ on S_1 (Fig. 1), a surface of constant elevation. The problem of continuing ΔT (x, y) into the space above S_1 to some point P (x, y, z) is a matter of solving equation (3) subject to certain boundary conditions, viz., the solution ΔT (x, y, z) reduces to known values on S_1 and vanishes at great distances above it. This is a classic problem of mathematical physics known as the first boundary value problem (or the Dirichlet

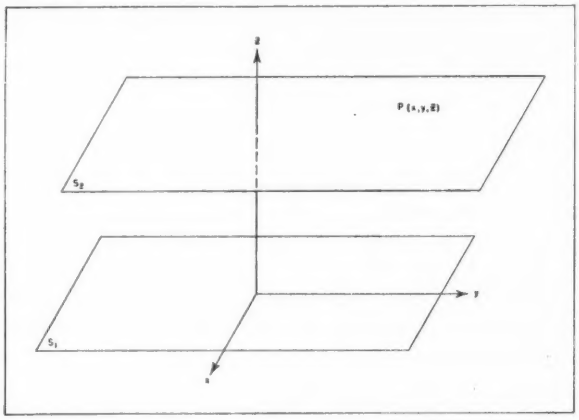

FIG. 1. Coordinate system and observational planes.

problem) for a plane. The solution may be obtained from Green's theorem with the aid of a Green's function of the first kind,[1] or following the development given by Byerly[2] the solution may be built up from particular solutions of equation (3) with the aid of the Fourier integral representation of $\Delta T\ (x, y)$ over plane S_1. Since the solution is unique, either approach leads to a solution of the form

$$\Delta T(x, y, z) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{z\Delta T(x', y')dx'dy'}{[z^2 + (x' - x)^2 + (y' - y)^2]^{3/2}}. \tag{4}$$

This solution is valid for $z>0$. The prime variables are the running coordinates of the plane S_1. There is no loss in generality if the origin is shifted so that the z-axis contains the point $P(x, y, z)$. Converting to cylindrical coordinates which are found to be more convenient for numerical evaluation, equation (4) becomes

$$\Delta T(z) = \frac{1}{2\pi}\int_0^{\infty}\int_0^{2\pi} \frac{z\Delta T(r, \alpha)rdrd\alpha}{(r^2 + z^2)^{3/2}} \tag{5}$$

where $x'=r\cos\alpha$, $y'=r\sin\alpha$. Equation (5) permits the computation of ΔT at any point of the positive polar axis. To compute the ΔT anomaly over some plane S_2 at a fixed height, h, above S_1 the constant value $z=h$ is inserted in equation (5) and the latter evaluated at a sufficient number of points of S_1 to permit the contouring of ΔT on S_2.

The evaluation of the integrals of equation (5) involves a very simple procedure. Noting that

$$\overline{\Delta T}(r) = \frac{1}{2\pi}\int_0^{2\pi} \Delta T(r, \alpha)d\alpha$$

where $\overline{\Delta T}\ (r)$ is the average value of ΔT on a circle of radius r, equation (5) becomes the simple integral

$$\Delta T(h) = \int_0^{\infty} \frac{hr\overline{\Delta T}(r)dr}{(r^2 + h^2)^{3/2}} \tag{6}$$

or

$$\Delta T(h) = \int_0^{\infty} \overline{\Delta T}(r)\phi(r, h)dr \tag{7}$$

where

$$\phi(r, h) = \frac{hr}{(r^2 + h^2)^{3/2}}.$$

To facilitate the determination of $\overline{\Delta T}\ (r)$, a square grid is superimposed over the anomaly and the values $\Delta T\ (x, y, o)$ are interpolated at each grid corner. A sheet

[1] Webster, A. G., *Partial differential equations of mathematical physics*, 2nd edition, pp. 222–225

[2] Byerly, W. W., *Fourier Series and Spherical Harmonics.*

of transparent paper is placed over the grid and with some corner as center, a family of n concentric circles passing through as many grid corners as possible is described. Each corner passed through is indicated by a dot on its respective circle. For each circle a coefficient

$$\phi(r_i, h) = \frac{hr_i}{(r_i^2 + h^2)^{3/2}}$$

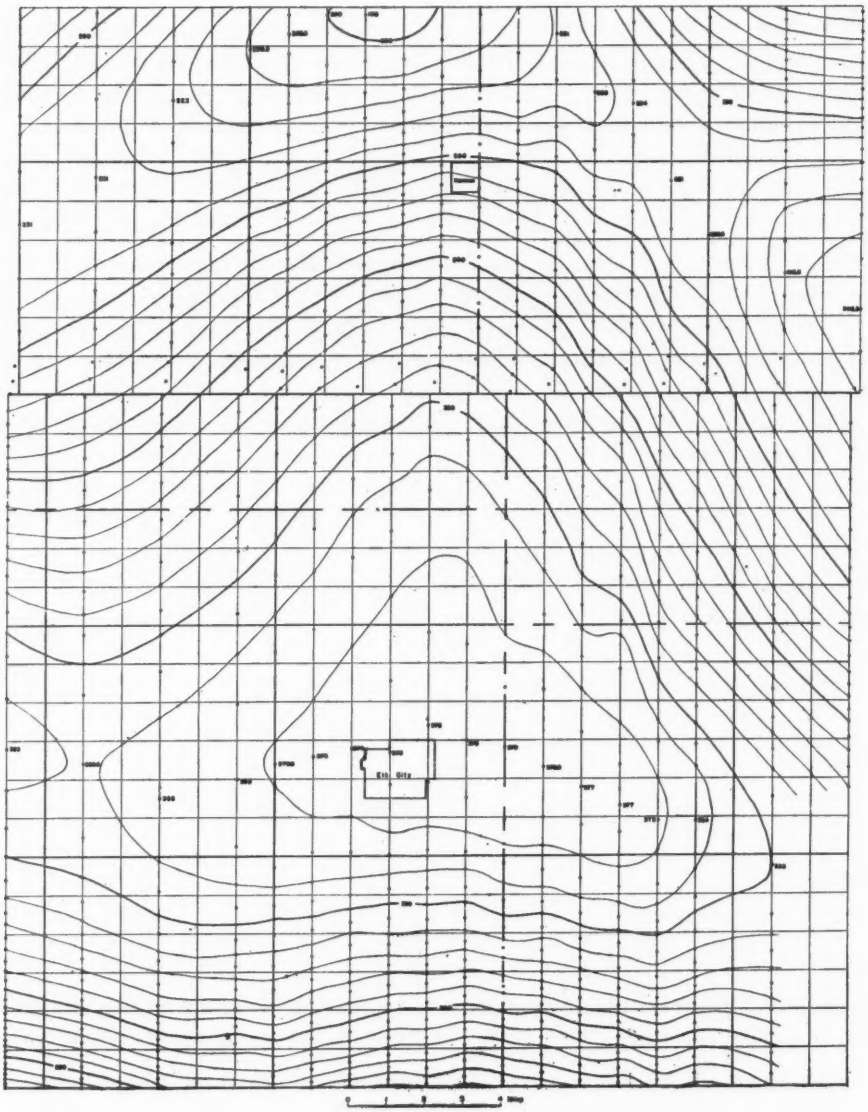

FIG. 2. Total intensity aeromagnetic map relative to arbitrary datum, Elk City, Oklahoma.

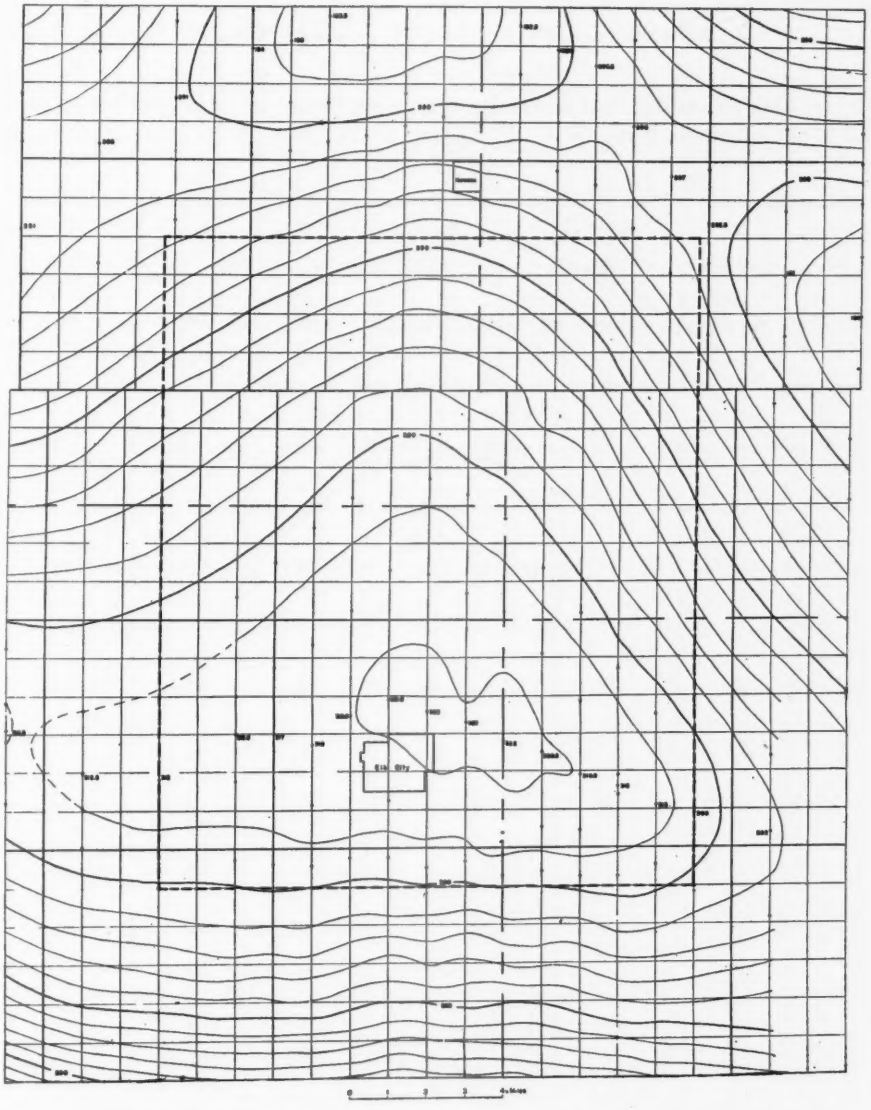

FIG. 3. Total intensity aeromagnetic map relative to arbitrary datum, Elk City, Oklahoma. (Flight level approximately 6,000 feet above ground and sea level.)

is determined where r_i is the radius of the *i-th* circle. The circle of radius $r_m = (h/\sqrt{2})$ on which $\phi(r_i, h)$ is a maximum should be included in the family. The products $\overline{\Delta T}(r_i)\phi(r_i, h)$ may be integrated by plotting and using a planimeter or by summing the areas of elemental trapezoids, keeping in mind the fact that the intervals along the v-axis are not evenly spaced. Using a trapezoidal rule, the integral in equation (6) may be replaced by the following approximation,

$$\Delta T(h) \approx \frac{1}{2}\sum_{i=1}^{n-1} \overline{\Delta T}(r_i)\phi(r_i, h)(r_{i+1} - r_{i-1}) + \frac{1}{2}\overline{\Delta T}(r_n)\phi(r_n, h)(r_n - r_{n-1}) \quad (8)$$

with the understanding that $r_0 = 0$. In view of equation (8) it is possible to determine a set of coefficients, $K(r_i, h) = \frac{1}{2}\phi(r_i, h)\ (r_{i+1} - r_{i-1})$ to use with the first

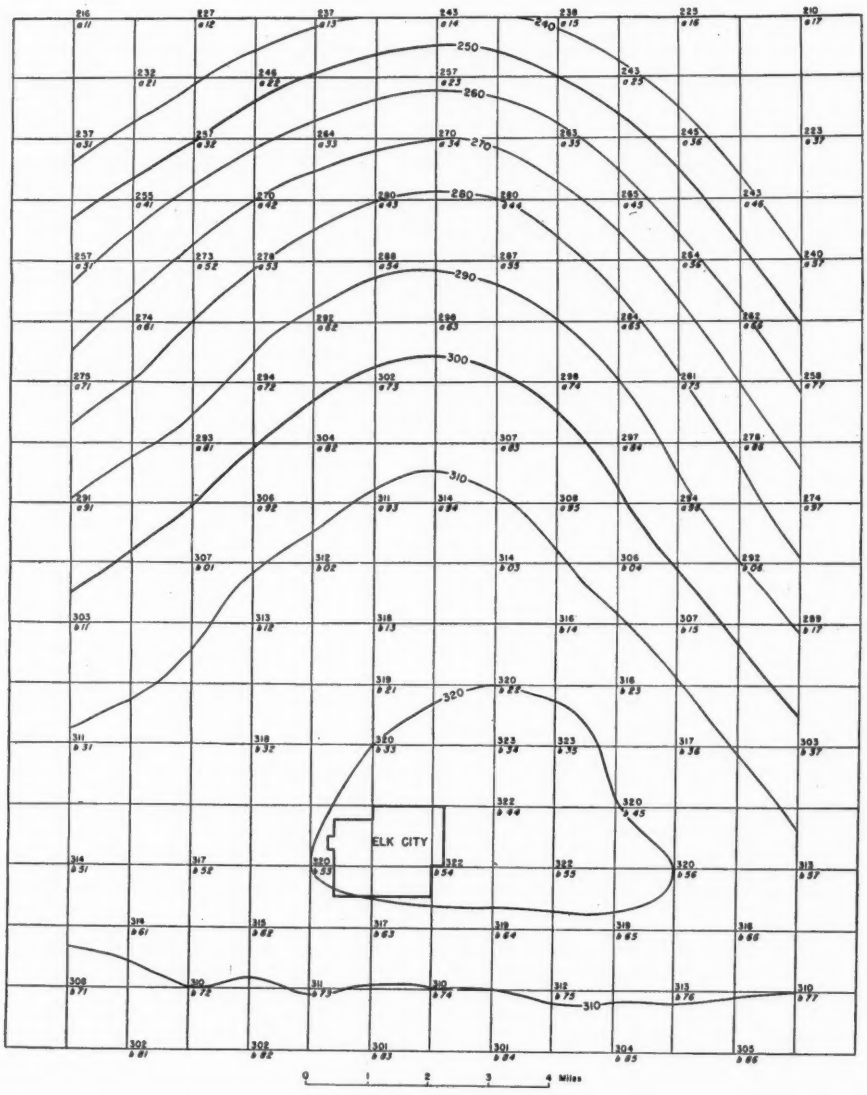

FIG. 4. Total intensity aeromagnetic map relative to arbitrary datum computed at 7,935 feet from aeromagnetic data observed at 2,935 feet, Elk City, Oklahoma. (Contour interval 10 gammas—elevations above sea level.)

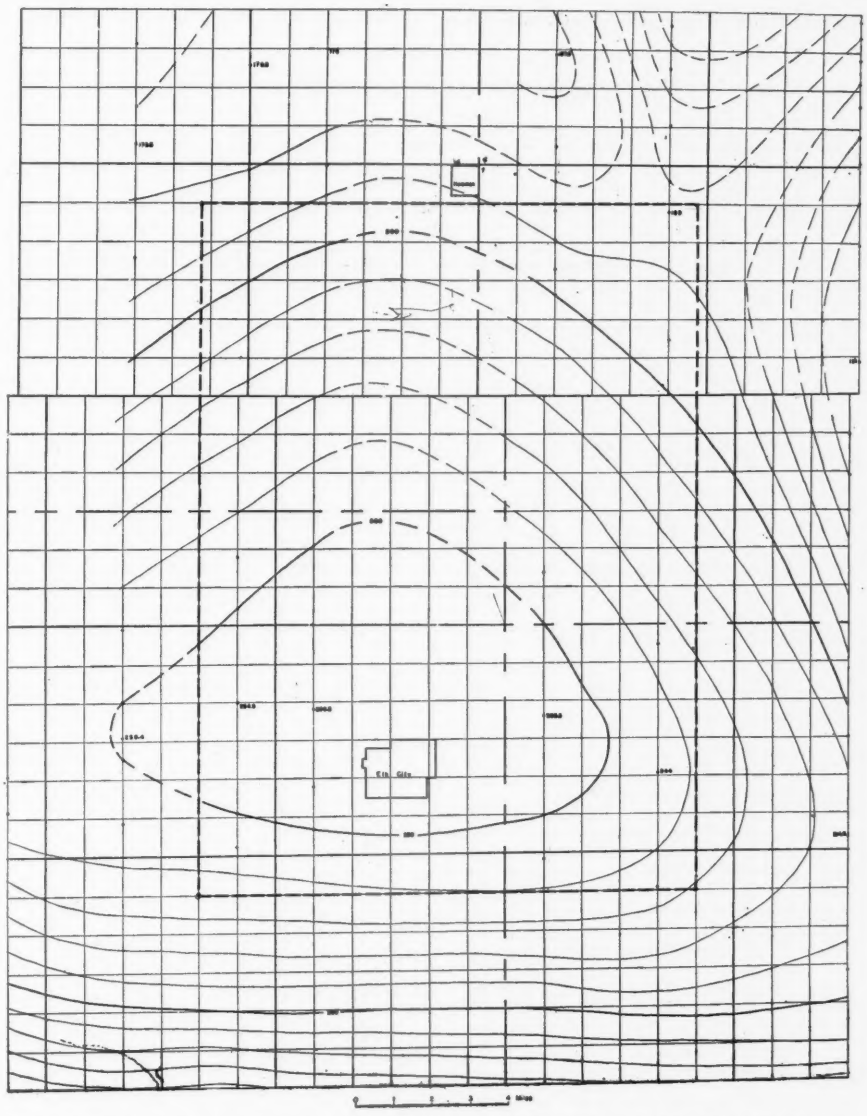

FIG. 5. Total intensity aeromagnetic map relative to arbitrary datum, Elk City, Oklahoma. (Flight level 15,935 feet above sea level—approximately 14,000 feet above ground.)

$(n-1)$ values $\Delta\overline{T}(r_i)$ and a coefficient $K(r_n, h)=\frac{1}{2}\phi(r_n, h)(r_n-r_{n-1})$ to use with the nth. The working formula is then

$$\Delta T(h) \approx \sum_{i=1}^{n-1} \overline{\Delta T}(r_i)K(r_i, h) + \overline{\Delta T}(r_n)K(r_n, h). \tag{9}$$

Theoretically, the integration is to be carried out over the entire plane; prac-

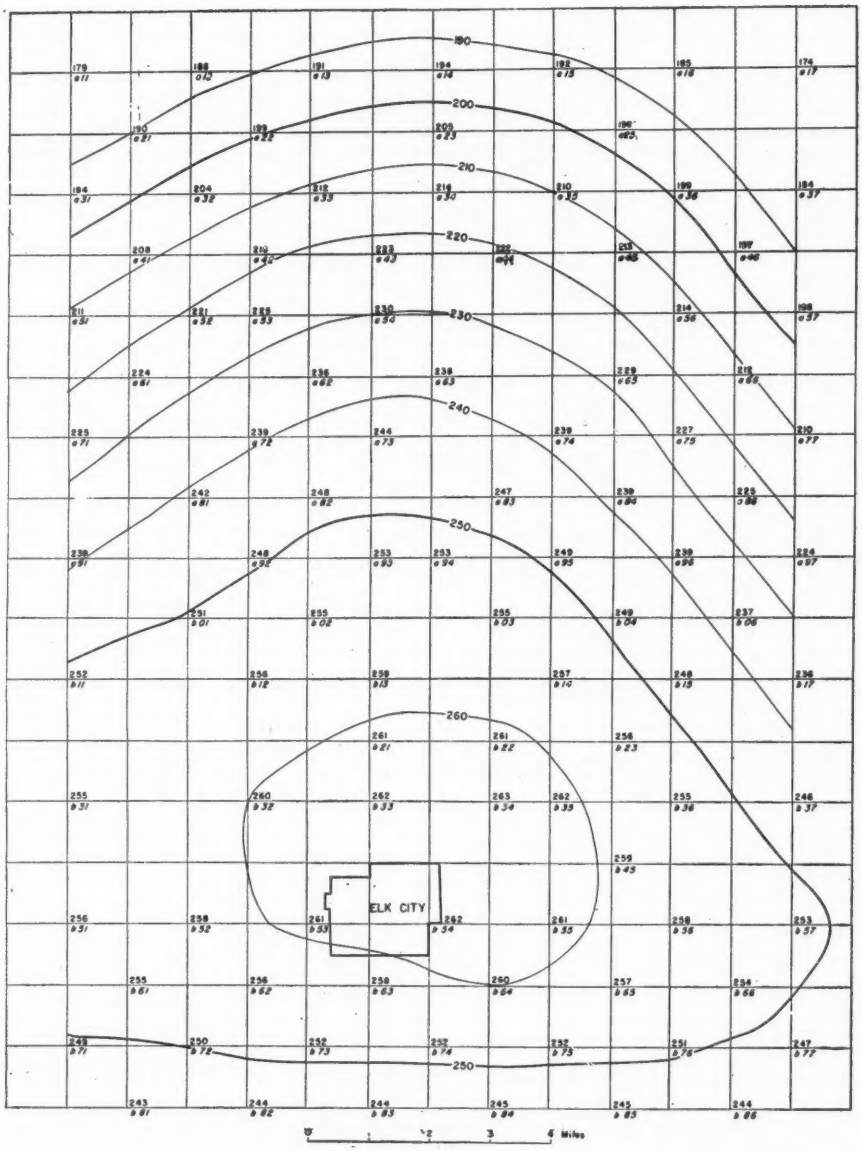

FIG. 6. Total intensity aeromagnetic map relative to arbitrary datum computed to 15,935 feet from aeromagnetic data observed at 2,935 feet, Elk City, Oklahoma. (Contour interval 10 gammas—elevations above sea level.)

tically it is not necessary, for, as r approaches some large value, the integrand in equation (7) is either negligibly small due to $\phi(r, h)$ being small or can be made so with impunity by arbitrarily smoothing to zero. When anomalies are complex and/or are of high gradient, the smoothing of the integrand to zero for large val-

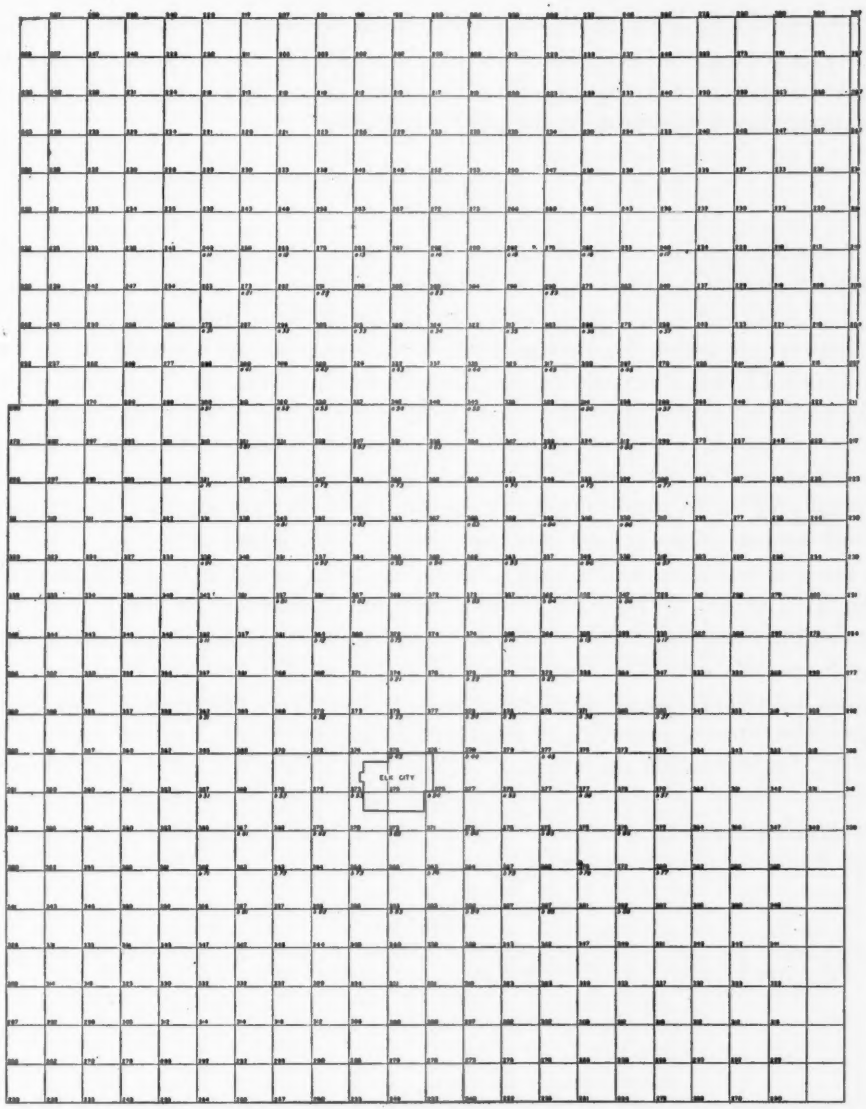

FIG. 7. Grid used in extension of Anomaly, Elk City, Oklahoma.

ues of r assumes no mean importance. It is necessary, therefore, to add to equation (9) a smoothing term

$$S = \frac{(r_n - r_{n-1})\left[\overline{\Delta T}(r_{n-1})\phi(r_{n-1}, h)\right]^2}{2\left[\overline{\Delta T}(r_{n-1})\phi(r_{n-1c}\, h) - \overline{\Delta T}(r_n)\phi(r_n, h)\right]}$$

where r_n is the radius of the outermost circle and $\overline{\Delta T}(r_{n-1})\phi(r_{n-1}, h) > \overline{\Delta T}(r_n)\phi(r_n, h)$. The radius r_n can best be determined by plotting several representative inte-

grands and selecting the average r for which the curves begin to level off. In most cases r_n is so large that accurate determinations of $\overline{\Delta T}(r_n)$ are impossible, but this is not serious since $\phi(r_n)$ is very small. In case $\overline{\Delta T}(r_{n-1})\phi(r_{n-1}, h) \leqq \Delta\overline{T}(r_n)\phi(r_n, h)$ the smoothing should be done entirely by graphing.

CONTINUATION OF OBSERVED THREE-DIMENSIONAL ANOMALIES

As an illustration of the method of analytical continuation consider the aeromagnetic survey in the vicinity of Elk City, Oklahoma. The results on planes at 2,935, 7,935, and 15,935 foot elevations above sea level are shown respectively in Figures 2, 3 and 5. A 1-mile grid was laid down over the anomaly on the first level and ΔT was interpolated for the grid corners (Fig. 7). A portion of the data used in computing to the second level ($h = 0.947$ mile) is presented in Table 1. A set of circles (Fig. 8) of radii shown in column 1, Table 1 were used. In column 3 are given the coefficients $K(r_i, h)$ and in the remaining columns are found the averages $\overline{\Delta T}(r_i)$ reduced by 200. At the bottom of the last-mentioned columns is found the sum of the products of the items in that column with those of column 3. To each result there has been added a constant of 167 gammas to bring the computed values up to the datum of the observations on this level. A contour map of the computed values of ΔT is presented in Figure 4. Comparing the computed anomaly with the observed anomaly (Fig. 3), the contours agree generally within a half-contour interval, representing an average error of less than 5 percent. The agreement could be improved in several ways, e.g., by using more circles, by increasing the number of points on each circle, or by employing a correction term to smooth the integrands. A few points were recomputed incorporating these refinements, with the result that the average error was less than 2 percent. Furthermore, it is noted that the area which can be effectively

TABLE 1

COEFFICIENTS AND $\overline{\Delta T}(r)$ VALUES (FOR SAMPLE POINTS) USED IN COMPUTING TOTAL MAGNETIC INTENSITY FIELD TO 7,935 FEET FROM DATA AT 2,935 FEET ABOVE SEA LEVEL. AVERAGES HAVE BEEN REDUCED BY 200γ. ANOMALY IN VICINITY OF ELK CITY, OKLAHOMA

1 Radius r_i	2 $\phi(r_i)$	3 Coefficients $K(r_i; h)$	a_{42}	a_{96}	a_{94}	a_{63}	b_{36}	b_{15}	b_{14}	b_{24}	b_{12}	b_{32}
0.500	0.3860	0.1292	157	147	169	155	171	160	170	178	165	170
0.670	0.4059	0.1015	157	147	169	155	171	160	170	177	165	170
1.000	0.3624	0.1348	157	148	168	154	171	160	170	177	165	170
1.414	0.2715	0.1678	157	148	167	151	171	161	170	176	165	170
2.236	0.1478	0.1292	155	144	165	147	167	156	168	174	164	169
3.162	0.0832	0.0835	154	141	160	141	163	153	166	172	162	167
4.243	0.0489	0.0449	150	135	154	131	157	148	159	164	160	164
5.000	0.0359	0.0285	146	129	149	124	149	142	154	162	156	162
5.831	0.0268	0.0670	141	122	143	116	142	137	148	165	152	156
10.000	0.0093	0.0194	92	94	99	80	99	96	101	108	119	126
Computed anomaly + 167γ			306	294	314	298	317	307	316	323	313	318

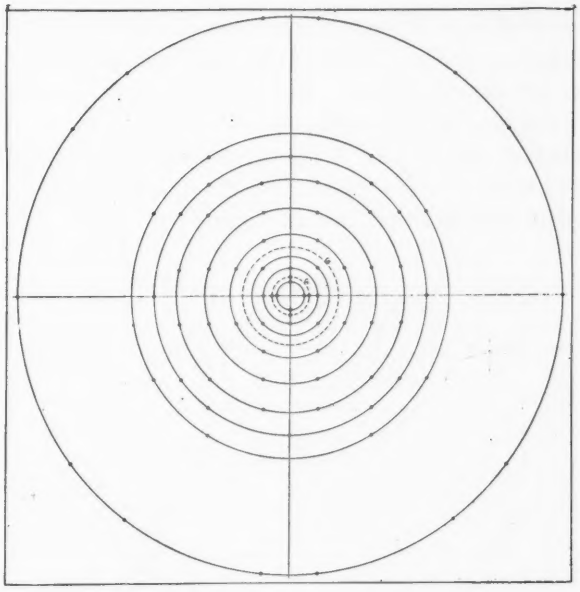

FIG. 8. Diagram for computing average values of ΔT on circles of radius r (C_1 and C_2 used only in computing to 7,935 feet and 15,935 feet respectively.)

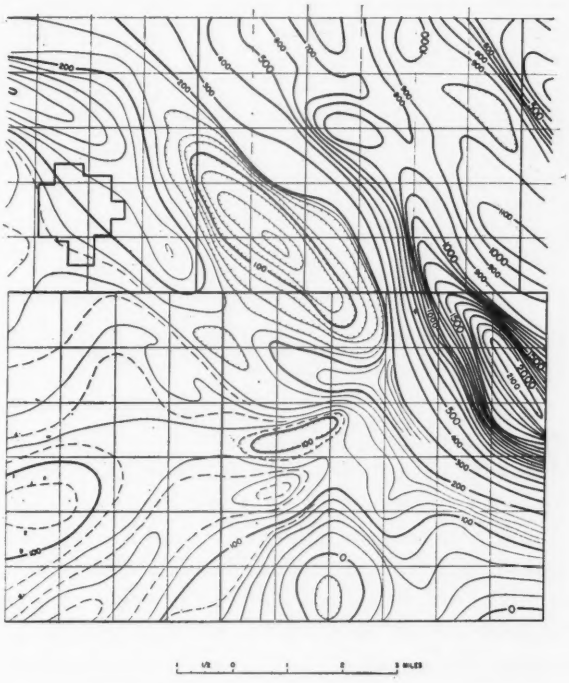

FIG. 9. Total intensity aeromagnetic map relative to arbitrary datum, Magnum, Oklahoma. (Flight level 1,935 feet above sea level—approximately 300 feet above ground.)

mapped on the second level by computation has its linear dimensions limited by the diameter of the largest circle. Since reducing the largest circle means sacrificing accuracy, for a given set of data the area which can be covered bears an inverse relation to the accuracy of computation.

As a further test of the method the data on the first level were used to compute to the third level ($h = 2.462$ miles). The results, presented in Figure 6, compare favorably with the observed data in Figure 5.

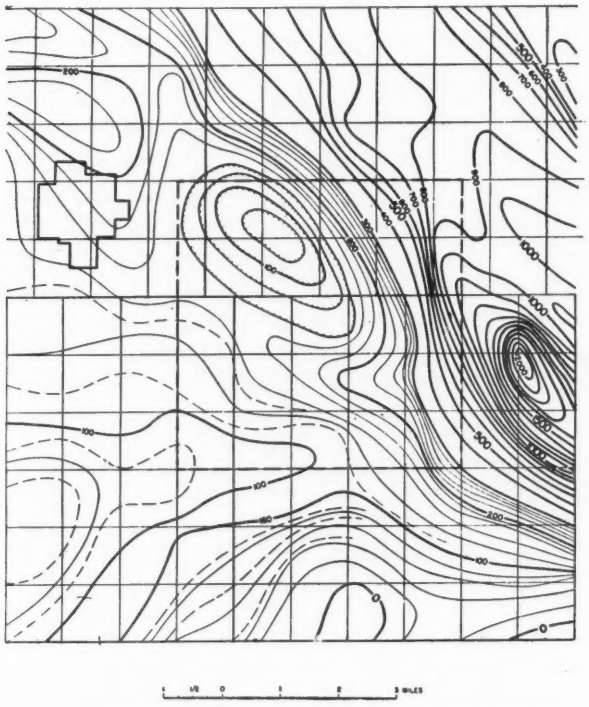

FIG. 10. Total intensity aeromagnetic map relative to arbitrary datum, Magnum, Oklahoma. (Observed at 2,935 feet above sea level.)

The general character of the Elk City anomaly is such that the success in extending it is not beyond expectation. The aeromagnetic survey in the vicinity of Mangum, Oklahoma, on planes 1,925, 2,935, and 7,935 feet above sea level affords a more exacting test of the method in view of the complexity, steep gradients and high amplitudes of the anomalies disclosed. (See Figs. 9, 10, 12.) Indeed with amplitudes of the order of 2,000 gammas it might well be inquired if the invariancy of the direction of the earth's normal field is still a tenable assumption. To some extent this question can be answered empirically by proceeding as before and checking computed against observed results. The $\frac{1}{2}$-mile grid used in effecting these computations was superimposed in such a manner as to coin-

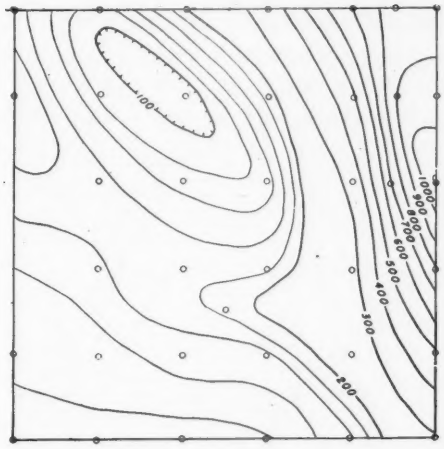

FIG. 11. Total intensity aeromagnetic map relative to arbitrary datum computed at 2,935-foot level from aeromagnetic data at 1,935 feet, Magnum, Oklahoma.

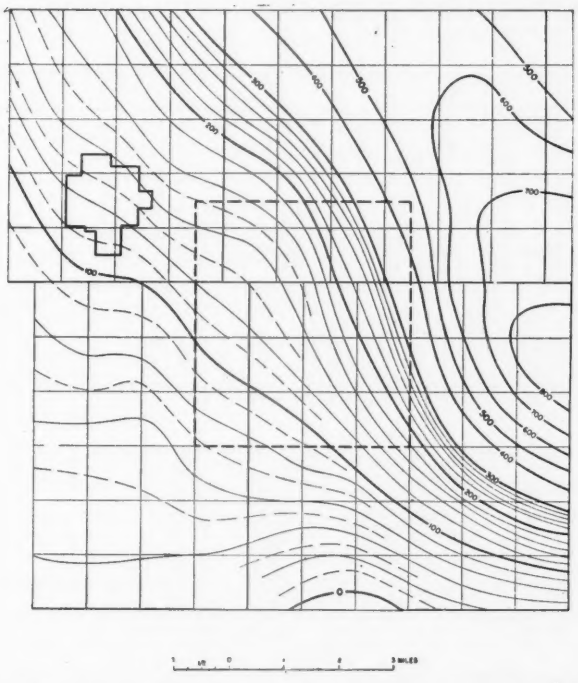

FIG. 12. Total intensity aeromagnetic map relative to arbitrary datum, Magnum, Oklahoma. (Observed at 7,935 feet above sea level.)

cide as nearly as possible with the flight lines. The smoothing term, S, was of non-negligible proportions and was applied routinely to all values.

In the extrapolation from the 1,935-foot level to 2,935 feet, a set of ten circles including one of radius $r=0.134$ mile for $\phi(r)_{max}$ and an outermost one of radius

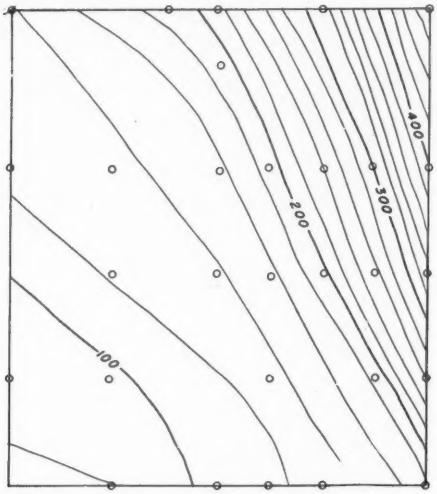

FIG. 13. Total intensity aeromagnetic map relative to arbitrary datum computed at 7,935-foot level from aeromagnetic data at 2,935 feet, Mangum, Oklahoma.

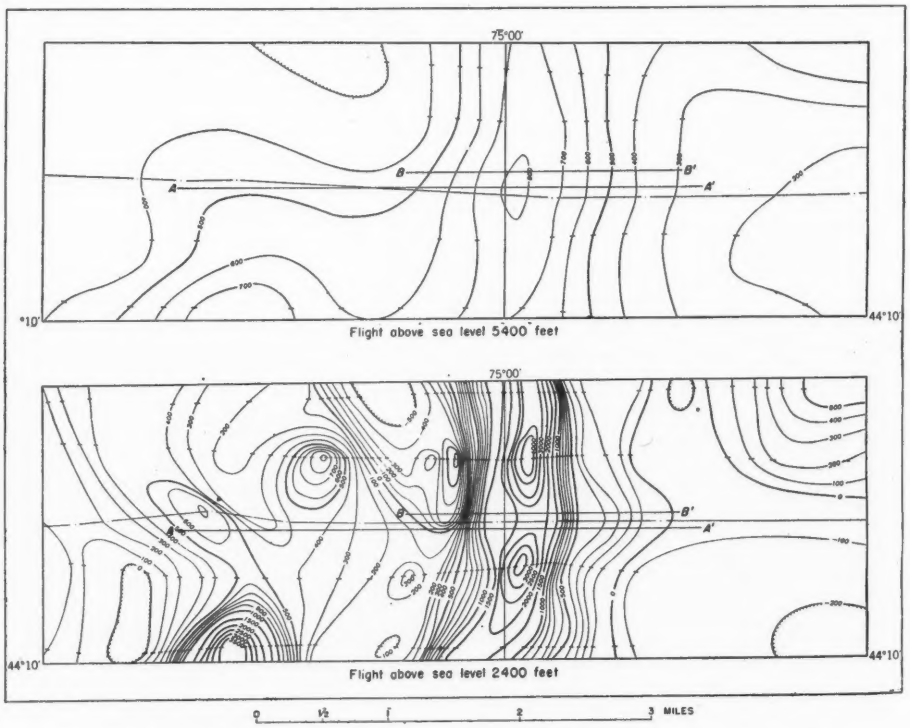

FIG. 14. Total intensity aeromagnetic map relative to arbitrary datum at two levels over Benson Mines, Saint Lawrence County, New York.

$r=4$ miles gave sufficient accuracy and coverage. A contour map of the computed values is shown in Figure 11 for comparison with those outlined in the central region of Figure 10. Except for a small area in the northwest corner of the former, the two are in excellent accord, the greatest discrepancy of any point being a contour interval.

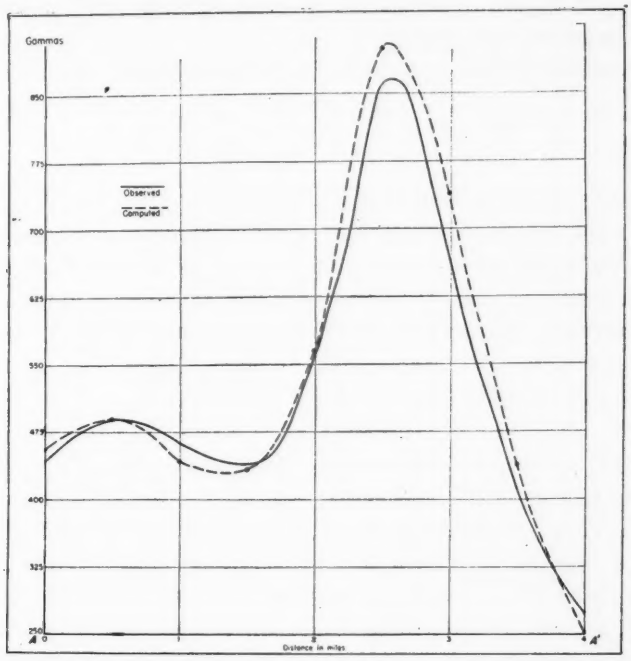

FIG. 15. Comparison between observed and computed profiles for the total magnetic intensity map of Benson Mines. (5,400 feet). Analytical continuation by three-dimensional method from data at 2,400 feet.

The continuation from the 2,935-foot level to 7,935 feet was achieved with similar success, as shown by a comparison between the computed values (Fig. 13) and the observed values (outlined area Fig. 12). A set of eight circles was used in this case. An attempt was made to improve the approximation to the surface integral by increasing the number of points on each circle as well as increasing the number of circles. The resulting values were insignificantly different from the original ones.

As another illustration, consider the aeromagnetic survey over the Benson Mines magnetite deposit, St. Lawrence County, N. Y. The results on the 2,400- and 5,400-foot levels are shown in Figure 14. Since the north-south dimensions of the area limit the diameter of the outermost circle of the set used in computing, only values at points along an east-west profile A-A' could be extended. A comparison between the observed and computed profiles is presented in Figure 15.

THE TWO-DIMENSIONAL CASE

Anomalies whose contours exhibit a tendency towards parallelism to the extent that transverse profiles are essentially alike may be regarded as two-dimensional. An example of an idealized two-dimensional anomaly is one produced by a line of poles. Since many geologic structures have well-defined strikes, e.g., the anomaly shown in Figure 14 near the 75th meridian, magnetic anomalies of this character are frequently encountered.

For the two-dimensional case the Laplace equation becomes

$$\nabla^2(\Delta T) \equiv \frac{\partial^2(\Delta T)}{\partial x^2} + \frac{\partial^2(\Delta T)}{\partial z^2} = 0 \tag{10}$$

assuming that ΔT does not depend upon the y coordinate, i.e., that a single profile paralleling the x-axis embodies the essential features of the anomaly ΔT.

A solution to equation (10) suitable for continuing values of ΔT into the space above the plane of observations can be obtained at once by integrating equation (4) with respect to y' and setting $y=0$. The equation becomes

$$\Delta T(x, z) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{z\Delta T(x')dx'}{z^2 + (x' - x)^2}. \tag{11}$$

Equation (11) is valid as long as $z>0$. To use equation (11) z is replaced by h, as before, and the integral evaluated for each point on the x-axis whose value is to be extended. To avoid integration over the entire x-axis, ΔT is arbitrarily smoothed to zero outside $a \leqq x \leqq b$, the essential range of the anomaly. Simplifications are introduced by taking ΔT at evenly spaced intervals. The integral may be evaluated by methods suggested above, i.e., by means of a planimeter, or by means of Simpson's or the trapezoidal rule. If the latter is used it is convenient to tabulate $\Delta T(x_i')$, $i=0, 1, 2, \cdots, n$, and to determine a set of coefficients

$$K(x_i', x, h) = \frac{1}{2\pi}\frac{h(x_{i+1}' - x_{i-1}')}{[h^2 + (x_i' - x)^2]}, \qquad i = 1, 2, 3, \cdots, (n-1),$$

which can be used repeatedly. The working equation is then

$$\Delta T(x, h) = \sum_{i=1}^{n-1} \Delta T(x_i')K(x_i', x, h). \tag{12}$$

As an illustration of the use of equation (12) consider the ΔT anomaly produced by a line of poles striking N. 44° 06′ W. (mag) in a total-intensity field of inclination 72° 05′ and located two units below the plane of observations. From the equation[3]

$$\Delta T = \frac{2m(x \cot I \sin \beta - d) \sin I}{x^2 + d^2}$$

[3] See the authors' "Analysis of Total Magnetic-Intensity Anomalies Produced by Point and Line Sources," *Geophysics*, Vol. 13, no. 3 (July 1948).

where β is the angle between the strike and magnetic north, m is pole strength per unit length, and I is the angle of inclination, the first level anomaly $\Delta T(x, 0)$ (column 2 of Table 2) was computed by setting $d=2$ and the second level anomaly $\Delta T(x, 4)$ (column 3 of Table 2) used in checking the accuracy of the extension to 4 units above the first level by setting $d=6$. The coefficients, $K(x_i', x, h)$ for $x=0$ are given in Table 3. In computing any other point in the range, it is clear that the same set of coefficients may be used, however they would be shifted with respect to the $\Delta T(x_i')$. It should be observed that $\Delta T(x, 0)$ has been arbitrarily smoothed to zero at $x=-14$ and $x=+9$. The values of $\Delta T(x, 4)$ obtained

TABLE 2

ANOMALIES PRODUCED BY LINE OF POLES 2 AND 6 UNITS BELOW PLANES $z=0$ AND $z=4$ RESPECTIVELY; AND ANOMALY ΔT CONTINUED TO $z=4$ FROM VALUES ON $z=0$

x	$\Delta T(x, 0)$ for $d=2$	$\Delta T(x, 4)$ for $d=6$	$\Delta T(x, 4)$
−14	0.0490	0.0751	
−13	0.0542	0.0828	
−12	0.0604	0.0920	
−11	0.0681	0.1027	
−10	0.0778	0.1154	
− 9	0.0901	0.1305	0.124
− 8	0.1063	0.1484	0.143
− 7	0.1284	0.1696	0.165
− 6	0.1594	0.1943	0.191
− 5	0.2050	0.2223	0.219
− 4	0.2759	0.2525	0.250
− 3	0.3916	0.2823	0.280
− 2	0.5827	0.3068	0.305
− 1	0.8468	0.3202	0.319
0	0.9515	0.3172	0.316
1	0.6756	0.2970	0.296
2	0.3687	0.2640	0.264
3	0.1940	0.2252	0.225
4	0.1047	0.1866	0.187
5	0.0574	0.1521	0.153
6	0.0309	0.1229	0.124
7	0.0153	0.0991	
8	0.0056	0.0799	
9	0.0006	0.0646	

TABLE 3

COEFFICIENTS TO BE USED WITH COLUMN 2 OF TABLE 2

$\pm(x_i')$	$K(x_i', h)$
0	0.07958
1	0.07490
2	0.06366
3	0.05093
4	0.03979
5	0.03105
6	0.02449
7	0.01959
8	0.01592
9	0.01313
10	0.01097
11	0.00929
12	0.00796
13	0.00688
14	0.00601
15	0.00528
16	0.00468
17	0.00417
18	0.00374
19	0.00338
20	0.00306
21	0.00279
22	0.00255
23	0.00234

by analytical continuation are given in column 4 of Table 2. The results indicate that the computation can be effected with surprising accuracy except in the neighborhood of the end points where the effects of smoothing become prominent. The accuracy was only slightly improved by reducing the interval by one-half.

The Benson Mines anomaly, Figure 14, suggests that a profile taken along *B-B'*, Figure 16, on the 2,400-foot level might admit of a two-dimensional analytical continuation. The results of the computation to the 5,400-foot level are shown in the upper half of Figure 16, where the observed (solid line) and the computed (dashed line) have been plotted using the same axis. The accuracy seems to be of the same order as that resulting from the three-dimensional treat-

ment above, cf. Figure 15. The three-dimensional approach has the advantage of yielding greater coverage, and the disadvantage of requiring more computational effort.

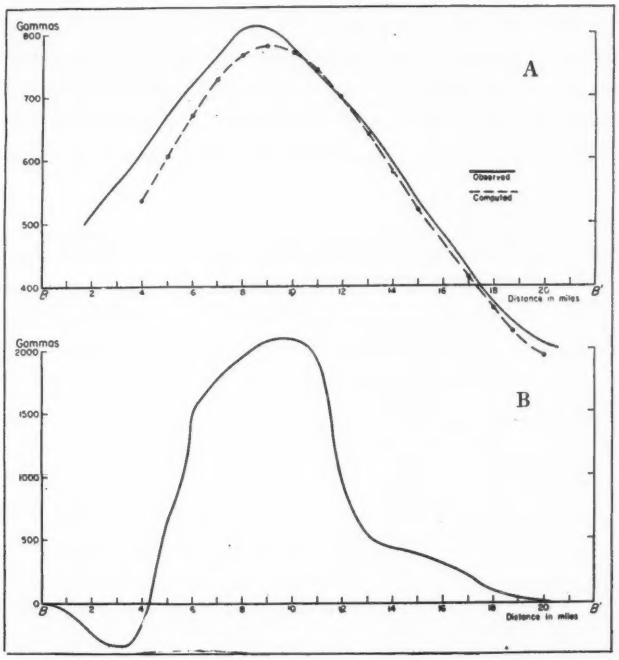

FIG. 16. Profiles for total magnetic intensity map of Benson Mines.

A. Comparison between observed and computed profiles at 5,400 foot level using two dimensional analysis.

B. Observed profile at 2,400 foot level.

CONCLUSION

The use of surface integrals affords a general continuation process and permits the detailed mapping, on higher levels, of fairly complex fields. It is significant that the process is in no way concerned with the geologic formations disturbing the field. In general the success of field extensions depends upon the number of points used in computing as well as the areal extent and complexity of the anomaly.

On the basis of the relative success met with in analytically continuing values of ΔT on one plane into the space above the plane, there is reason to believe that little is to be gained by conducting multi-level aeromagnetic surveys. There is inherent in the first-level data the essential information of the higher level. Indeed, if the latter is required, within the limits indicated, one computer can provide it at a much lower cost than that involved in field operations.

A PRECISION DETAIL GRAVITY SURVEY, JAMESON AREA, COKE COUNTY, TEXAS*

HART BROWN†

ABSTRACT

Since few, if any, conventional gravity surveys of the Jameson Area produced a significant gravity anomaly, an experimental high density gravity survey was conducted immediately following the field discovery. A station density of 15 per square mile was achieved. Great pains were taken to obtain higher than customary precision of each field measurement. Careful terrain corrections were applied. Maps of observed and residual gravity are presented.

The subsequent drilling of some 36 field wells now provides an accurate reef map. This reef map is compared with the gravity anomaly to bring out the degree of correlation which may be expected from other similar reefs.

INTRODUCTION

This paper is a report on an experimental gravity survey covering about 20 square miles surrounding the discovery well at Jameson. The project was started shortly after the completion of the discovery well. Sun Oil Company was most helpful, first by granting permits, access to logs etc., and second by their discussion and criticism of results obtained. This particular area was chosen for the experiment because conventional gravity maps, available before the oil discovery here, had failed to reveal a significant anomaly, and it was thought that perhaps a survey using 4 or 5 times the customary station density might detect a weak anomaly associated with the field.

REGIONAL GRAVITY

Figure 1 is taken from a reconnaissance gravity map covering most of Texas. The contour interval is one milligal, which is four times that used on conventional maps. Control point density is about 1/20 that used on conventional surveys. The rectangular block measuring about five miles by eight miles outlined in the center of Figure 1 is the area which was selected for close detail in this experiment. The discovery well is near the center of this rectangle. Subsequent figures will show only the area included in this small rectangle. Note that the Jameson Area lies on a relatively uniform regional gravity surface decreasing from a maximum closure in Runnels County to a minimum closure in Mitchell County. These data exhibit no significant anomaly at the Jameson Field although there is a decided maximum axis some twenty miles long a short distance south of the Jameson Area. It seemed apparent from these data that only a meticulously conducted survey could possibly detect the reef, which had then been discovered by the Jameson well, or to define the reef's boundaries.

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† Brown Geophysical Company, Houston, Texas.

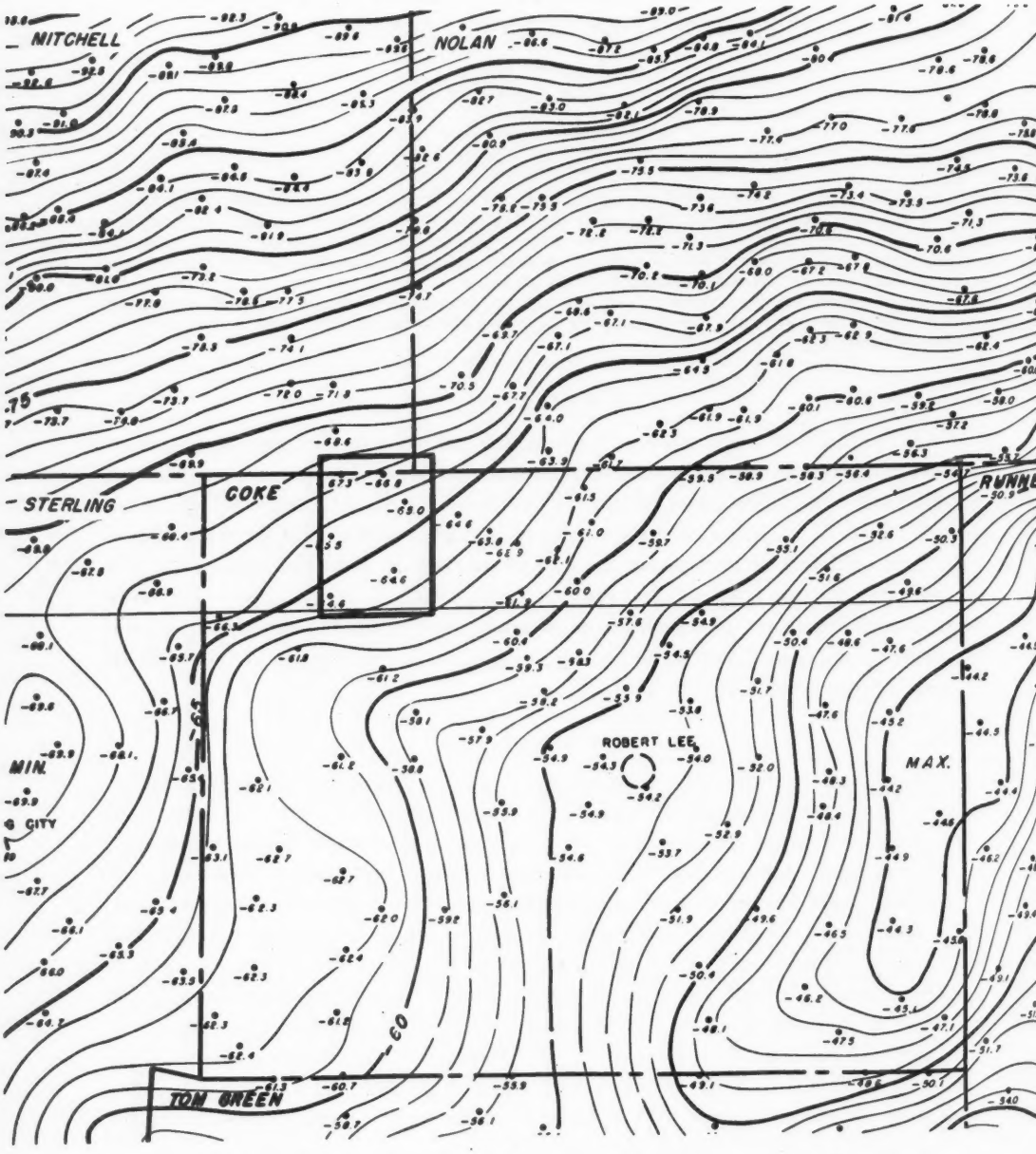

FIG. 1. Regional Gravity surrounding the Jameson Field. Contour interval is one milligal. (Scale, 1:500,000)

CONVENTIONAL GRAVITY

Figure 2 shows a conventional gravity survey of the area outlined in Figure 1. The discovery well is shown. Gravity values shown here are spaced at half mile intervals and produce a map having about 2.5 stations per square mile. This station density has resolved some minor trends which the reconnaissance map

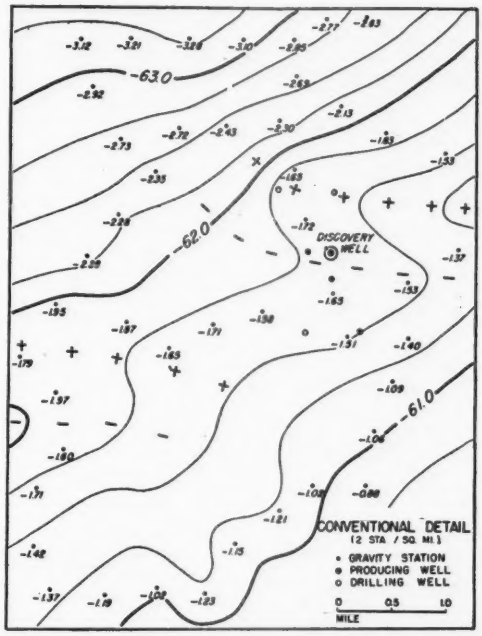

FIG. 2. Conventional Gravity Survey of an area immediately surrounding the Jameson discovery well and suggestions of east-west trends. Gravity values are in milligals. The four completions and three drilling wells show status of development at the time these maps were prepared.

failed to reveal. These trends apparently bear east and west. The maximum trend is marked by plus signs and the minimum trends by minus signs. The anomaly present near the well would be of little help in leading to the discovery of the field or in outlining the edge of the reef after the field had been discovered.

PRECISION DETAIL GRAVITY

Figure 3 shows the gravity contours resulting from a survey using an average density of 15 stations per square mile. The contour interval is 0.10 milligal. The principal maximum gravity axis is shown by the row of plus signs, and the dominant minimum axes are shown by the rows of minus signs. Note that the outstanding maximum axis now trends north and south rather than nearly east and west as it appeared to do in Figure 2. Note also the continuity of the small

sharp minimum axis surrounding the gravity maximum. The discovery well lies about halfway between the maximum axis and the eastern minimum axis.

FIELD PROCEDURES

It is necessary that small anomalies such as those contoured in Figure 3 be based upon thoroughly dependable data before confidence can be placed in them.

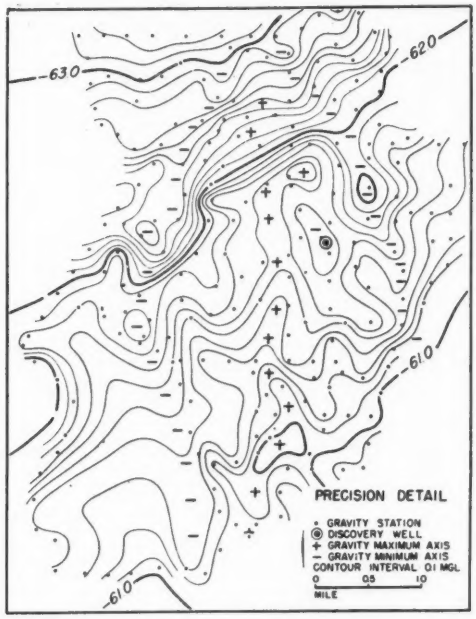

FIG. 3. Precision Detail Gravity map of Jameson, resolving north-south trends. Contour interval is 0.10 milligal.

(Remember this contour interval is 0.10 milligal.). On a conventional gravity map it would seem justifiable to throw out almost any of the anomalies resolved here since their magnitudes are of the same order as the probable error. Anticipating such a problem, the field work was conducted so as to yield individual gravity values which would be several times as dependable as those obtained by conventional field techniques. Surveying loops were kept very small, usually about 1.0 mile by 0.25 mile, thus minimizing errors in individual station elevations and locations. Each station location was staked and the gravity meter observed directly over the stake. An accurate topographic map was needed to determine the elevation correction factor and terrain corrections. Such a map was prepared in the field using all prominent topographic features in addition to the elevations of the gravity stations and intermediate points.

Elevation correction factors were determined separately for the south part and the north part of the area. This was done because the north portion was

essentially a limestone surface whereas the south portion was essentially a sand surface. The factors so determined were so nearly equal that one common factor was used for the computation of all stations. Terrain corrections were computed and applied to 90 of the 215 stations shown here. Since 75 per cent of the station locations could not be reached in a Ford car, Jeeps were used for virtually all work. The rough ride the gravity meter undergoes in crossing rough fields in a

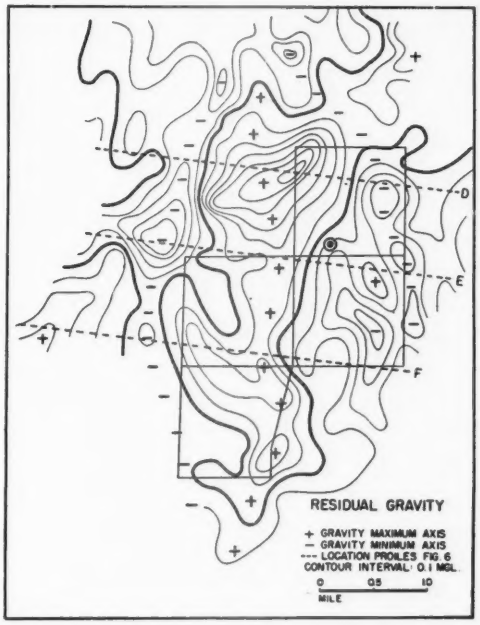

FIG. 4. Residual Gravity as computed from Figure 3.

Jeep adversely affected its precision, at the very time when increased precision was demanded. To combat this the observed gravity values for all stations were checked by a second run, the two runs being made on different days so they would be entirely independent of each other. To obtain checks within 0.06 milligal it was found necessary to run about 40 per cent of the stations a third time, ten per cent a fourth time, and some stations a fifth or sixth time. One surveyor working three or four days a week kept the gravity meter busy six or seven days a week. Obviously the field crew personnel and procedures were radically different from the conventional arrangements.

RESIDUAL GRAVITY

Figure 4 shows the residual anomaly as computed from the data shown in Figure 3. The maximum axes (plus signs) and the minimum axes (minus signs) are shown in the identical positions on both Figure 3 and Figure 4. Note the

location of the discovery well. By the time these maps were completed Sun Oil Company had four reef producers and one well drilled to the Ellenberger with a show in the Ellenberger. There are surface structure indications and seismic indications which led to the selection of the discovery well site. In the light of all these data it was surmised that the minimum axis outlined the shape of either an Ellenberger structure, or the reef, or both; and that the maximum axis marked its apex.

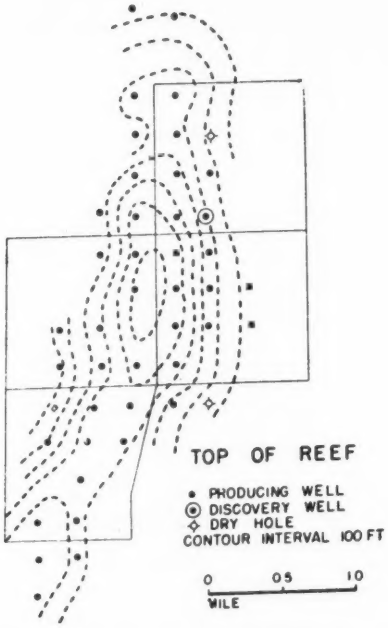

FIG. 5. Contours showing the top of the reef (about 6,000 feet deep) as defined by all field wells drilled as of February 1949. This map is directly comparable with Figure 4 and Figure 3.

SUBSURFACE MAP

Figure 5 shows 100 foot interval contours on top of the reef determined from completed field wells as of February 1949. The correlation between these contours and the gravity contours on the residual map (Fig. 4) is obvious. Four or five of the field wells shown were carried to the Ellenberger, and have revealed no appreciable structure or relief on the top of the Ellenberger. Similarly, field well logs show very little closure as existing in any of the markers from the surface down to within a few hundred feet above the reef. It therefore seems quite conclusive that the gravity anomalies shown in Figures 3 and 4 are primarily due to the limestone reef replacing the normal Pennsylvanian shale section at this location.

THEORETICAL GRAVITY

Figure 6 shows an attempt to determine theoretically what portion of this gravity anomaly can be credited directly to the Strawn reef development; and, if possible, what portion of the anomaly must have been produced by other factors. On Figure 4 the dashed lines D, E, and F are positions selected for three representative gravity profiles across this anomaly. The gravity values along these profiles are plotted in Figure 6A as the three solid curves. The average of these three curves is shown by the heavy dashed curve. In Figure 6C a simplified repre-

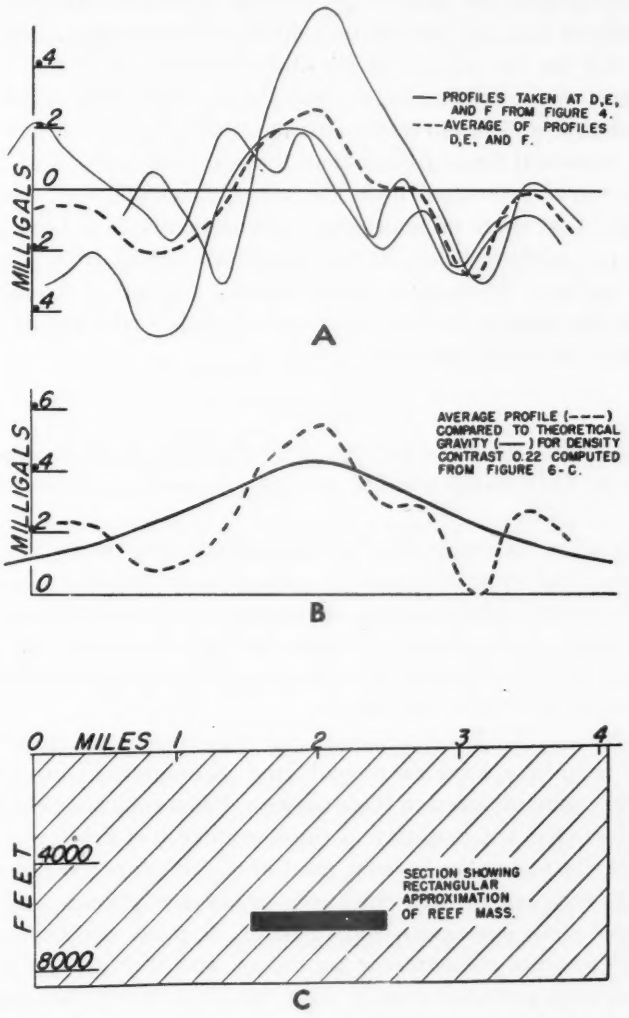

FIG. 6. Theoretical gravity anomaly computed from an approximate reef form, compared with gravity profiles as measured at Jameson.

sentation of the Jameson reef is shown to scale in section. The rectangular cross sectional shape was used because the theoretical gravity was then easy to compute. Figure 6B compares the theoretical gravity computed from Figure 6C with the average observed gravity obtained from Figure 6A. A density contrast of 0.22 gm/cm^3 for the limestone reef compared to its surroundings, was arbitrarily chosen because this value produced a theoretical graph which seemed best to account for the observed curve. The observed curve has been superimposed on the theoretical by raising it about 0.20 milligals to obtain the best fit. From this it appears that a reef of the general magnitude of that at Jameson, buried about a mile deep could account for most of the gravity maximum observed here if the reef has a density of 0.22 gm/cm^3 greater than its surrounding medium.

However, note the two minima on the observed curve, one a mile east, and the other a mile west of the center of the gravity apex. Note how narrow and sharp these two minima are. The curvature of the observed curve, where it produces these minima, is several times greater than the curvature present at any point on the theoretical curve calculated from the buried limestone reef. The conclusion must be reached that these minima cannot theoretically have been produced by the reef itself or anything below it; but must have arisen from some condition closer to the surface. Apparently these minima cannot be accounted for by phenomena on the surface, such as differences in soils, or by failure to make the proper terrain or elevation corrections.

CONCLUSION

A precision detail survey as herein described, costs about $150.00 per square mile to conduct. This makes blanket coverage as used in conventional surveys impractical.

When large areas are mapped in this detailed manner, the survey produces so many anomalies that some independent geological or geophysical information is then required to decide which, if any, of the gravity anomalies point to reefs.

Figure 6 shows a theoretical criticism to the conclusion that the gravity anomaly at Jameson results solely from the limestone mass in the Pennsylvanian, buried about 6000 feet below the surface.

Since completing the Jameson area, some five crew years of surveys seeking reefs, by this technique, have been conducted. Numerous known reefs, well defined by drilling, were included in these surveys. From such studies the conclusion must be reached that the majority of the limestone reef fields will not produce the desired gravity anomalies because most of the reefs are too deeply buried, or are too broad compared to their thickness, or the gradation from the reef limestone to normal shale covers too wide a band. It must also be concluded that many reefs do produce measureable anomalies, and that gravity surveys using closely spaced, high precision gravity data, comprise a valuable tool in selected areas, especially when combined with otherwise inconclusive geological data.

ELEVATION SURVEYING BY PRECISION BAROMETRIC MEANS*

A. A. STRIPLING,† R. A. BRODING,† AND E. S. WILHELM†

ABSTRACT

A sensitive instrument for measuring changes in atmospheric pressure and adapted for use in elevation surveying is described.

Differences in atmospheric pressure are measured by measuring the changes in volume of an isothermal gas chamber that are required to maintain the chamber at atmospheric pressure. The instrument is sensitive to a change in atmospheric pressure equivalent to an elevation difference of 0.1 foot.

Some of the theoretical aspects relating barometric pressure to elevation are reviewed, and the practical limitations imposed by the erratic nature of the atmosphere are discussed. Two field techniques are described, and a typical survey around an eight mile loop of thirteen stations is presented in which the closure is 1.2 feet, and the average error is 0.8 foot.

INTRODUCTION

The use of a barometer as an instrument for measuring difference in elevation between points on the earth's surface is an old and well-known art. The first evidence of the variation of pressure with altitude was furnished in the seventeenth century by Pascal, who showed that the mercury column of Torricelli's newly invented barometer was not as high on a mountain-top as it was in the valley below. Laplace's formula, developed early in the nineteenth century, forms the basis for computing elevation difference from barometric measurements at the present time.

Aneroid barometers have often been used in geological surveying. By continuously observing the drift in atmospheric pressure with one or more base barometers, corrections can be determined and applied to the readings of a field barometer with sufficient accuracy to permit the measurement of elevations to within the order of five feet. The accuracy of such a survey depends upon the stability of the atmosphere, and under unfavorable conditions errors much greater than five feet will be encountered.

The measurement of elevation differences to within five feet is far from satisfactory for most geophysical operations. In gravity surveying, the elevation differences between stations should be known with a probable error of approximately 0.5 foot, in order that the changes in gravity caused by changes in elevation can be computed and subtracted from the measured changes. This correction, among others, is necessary in order to remove from the gravity data all effects except those due to the subsurface geological structures, the finding of which is the goal of the survey.

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Where some means of establishing horizontal control other than the conventional transit survey is available, the use of barometers to determine elevations would be a real advantage in gravity surveying. The barometers could be read along with the gravimeters at each station, thus eliminating the necessity of an auxiliary survey. Increasing the accuracy of barometric elevations requires the development of a field technique which will eliminate the large variations which constantly occur in the atmosphere and the construction of an instrument of high sensitivity so that small pressure differences, representing real elevation differences, may be detected.

In this paper, a recently developed barometer of high sensitivity, designed for use as an elevation meter, and a field technique for its use are described. Laplace's original work is briefly reviewed, and the modifications used in computing data obtained with the new elevation meter are discussed. The results of a survey made May 14, 1948, are included.

THE INSTRUMENT

The basic design of the elevation meter was originated by George Conover of the Geophysical Department, Magnolia Petroleum Company. A schematic diagram illustrating the principle of operation is shown in Figure 1. The funda-

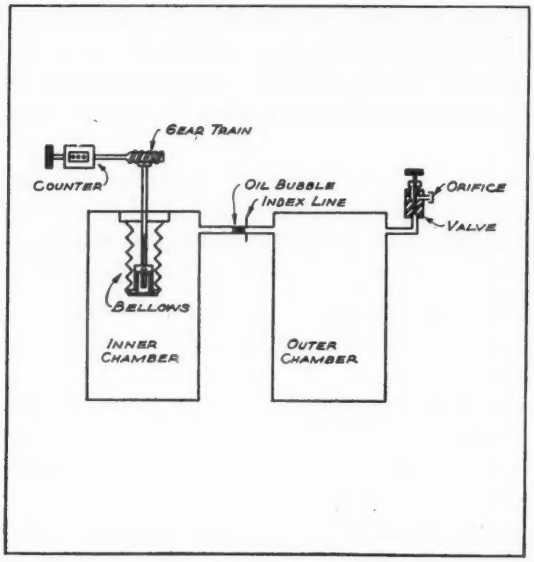

FIG. 1. Schematic diagram illustrating operating principles of the elevation meter.

mental component of the meter is a gas-filled chamber maintained at nearly constant temperature. This chamber contains a bellows that accurately regulates the volume of the chamber. Therefore, since the temperature is held constant,

the bellows accurately regulates the pressure within the chamber. This pressure is balanced against the atmospheric pressure registered in the outer chamber, which is opened to the atmosphere through the valve and the orifice. This balance is established when the meniscus of the small oil column coincides with the index line etched on the transparent tube connecting the two chambers. The bellows movement necessary to effect a balance when the pressure in the outer chamber changes is registered on the counter. Thus, the change in the counter is a measure of the change in atmospheric pressure corresponding to a change in elevation. The scale of the counter has a range of 1,000 units corresponding approximately

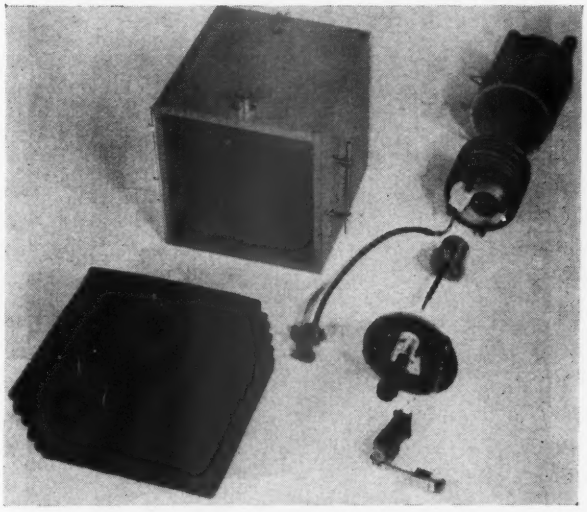

FIG. 2. Exploded view of the instrument.

to 1,100 feet. The instrument is so constructed that the scale may be reset to zero at any time, and the measuring range extended indefinitely.

The design of the oven assembly used to maintain close temperature control on the components within the oven was based upon studies made by Clewell[1] and by Clapp.[2] Figure 2 shows an exploded view of the instrument in which the oven assembly is shown in detail. Beginning at the upper right-hand corner and moving to the lower right, the following components are shown: aluminum oven wound with heater wire, the inner and outer chambers assembly with a connecting tube to the valve, the bellows assembly, the top plate of the oven, and the counter

[1] Clewell, Dayton H., "Problems in Temperature Control of Gravimeters." *Geophysics*, 7, No. 2 (April, 1942), 155–168.

[2] Clapp, J. K., "Notes on the Design of Temperature Control Units, "*General Radio Experimenter*, *XIX*, No. 3 (August, 1944), 1–7.

assembly. At the left is shown the aluminum case and a portion of the felt used as insulating material. The white lucite block visible on the chambers assembly contains the low vapor pressure oil which is used to indicate the pressure balance as previously described. The copper tubing around the outside of the assembly serves to pre-heat any air entering the outer chamber. On the oven top plate may be seen the telescope for viewing the oil column. On the right hand side of the top plate is one of the precision thermostats which operates through a relay to open and close the heater circuit. A second thermostat is located on the bottom of the

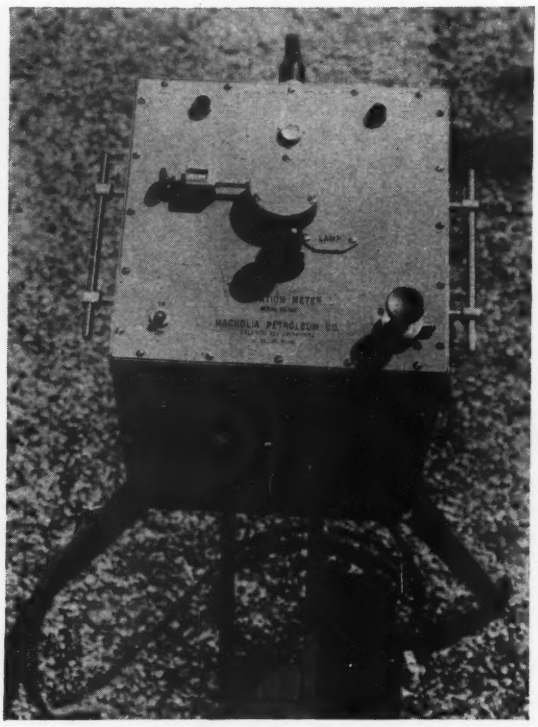

FIG. 3. Top view of the instrument.

oven. The heater circuits are divided so that the top thermostat controls the top heater coil and the bottom thermostat controls the bottom heater coil.

The thermostats maintain a temperature of 45°C. with an operating differential of ±0.02°C. A layer of felt between the inside wall of the oven and the controlled chambers serves as a low pass thermal filter and effectively reduces the variations caused by the operating back-lash of the thermostats. The variation of the temperature of the controlled space is of the order of ±0.001°C.

Heat control is lost when either the on or off period is 90 percent or more of the thermostat cycle time. A test was made to determine what variation could be

tolerated in the ambient temperature. It was found that the heaters were on 90 percent of the total time when the room temperature was 10°C. The heaters were off 90 percent of the time when room temperature was 40°C. Two pilot lights are mounted on top of the instrument case to indicate the on-off periods of the thermostats.

The power for the heater circuits and the lamps on the instrument is furnished by a 6 volt motorcycle battery. Figure 3 is a top view of the instrument mounted on a tripod and connected to the battery. The pilot lamps, bull's-eye level, counter, eyepiece, switch, and the valve with orifice at the right may be seen. The weight of the instrument is 21 pounds.

SENSITIVITY OF THE INSTRUMENT

Other barometers used as altimeters have definite limitations. The mercurial barometer has not been successfully developed into a field instrument. It is unwieldy, fragile, and sensitive to temperature changes. The aneroid barometer has been widely used in elevation surveying. It is generally subject to errors caused by friction, elastic hysteresis, and lag. The most careful construction is necessary to eliminate error due to temperature changes. Even when these errors have been reduced, there is a scale compression such that readings can be made only to the nearest foot.

In this instrument the above mentioned sources of error have been eliminated almost entirely. The index oil moves in a horizontal tube, so that the effect of gravity on the mass of the oil is constant. The only friction present in the instrument is the small resistance of an oil bubble flowing in a lucite tube. This is minimized by the use of low viscosity, low vapor pressure oil, so that friction is negligible within the sensitivity of the instrument. Hysteresis in the bellows is negligible since the bellows is maintained at constant temperature and works between the limits 10 percent compression and 25 percent compression.

In designing the instrument it was considered desirable to have one unit on the counter be equivalent to approximately one foot elevation change. It was also desirable to detect pressure changes corresponding to one-tenth of a counter unit, i.e., one-tenth foot change in elevation. The distance the oil moves in the tube for a given pressure change varies directly as the volume of the inner chamber and inversely as the cross-sectional area of the tube. In bringing the oil meniscus back to the index line, an equal pressure change is effected in the inner chamber by means of the bellows. The amount of movement of the bellows is a function of its effective area and the volume of the inner chamber. If A is the cross-sectional area of the index tube, d is the distance the oil moves per counter unit, a is the effective area of the bellows, and k is the distance the bellows moves per counter unit, then

$$dA = ak = \Delta V,$$

where ΔV is the change in volume of the inner chamber per counter unit. For the

material used in constructing the index tube and the type of oil used in the tube, it was found that the best diameter was 0.086 inch, since oil in a smaller tube tends to separate into bubbles while larger diameters reduce the sensitivity. It was also found that 0.01 inch movement of the oil was the minimum movement for easy resolution by the eye. This 0.01 inch movement must then correspond to an elevation change of one-tenth foot. Thus, d the movement of the oil per counter unit, is fixed at 0.1 inch, and A, the cross-sectional area of the tube, is fixed at 0.0058 square inch.

Since the inner chamber is at constant temperature, Boyle's law applies so that

$$\Delta V/V = -\Delta P/P,$$

where $\Delta V/V$ is the ratio of the change in volume per counter unit to the total volume of the inner chamber, and $\Delta P/P$ is the ratio of the change in pressure for one foot elevation change to the total pressure. Now ΔV is a fixed quantity determined by the requirements for dA, and the ratio $\Delta P/P$ is a fixed quantity determined by the density of the atmosphere. Therefore, the volume of the inner chamber and the bellows dimensions can be computed to give the required sensitivity.

It is interesting to note that there is a significant change in sensitivity from one end of the scale to the other. As the counter increases from 0 to 1,000, the bellows length decreases, and the inner chamber volume increases. Thus, a change in the counter from 0 to 1 produces a different ratio $\Delta V/V$ from the ratio produced by the change from 999 to 1,000. The change in sensitivity from one end of the scale to the other is 4 percent, and a graph plotting a calibration factor against counter number could easily be drawn. This has been done, but other factors have been combined with the change in scale sensitivity to produce the graph actually used.

THEORY OF BAROMETRIC ALTIMETRY

In order to determine the relationship between the constants of the instrument and the changes in barometric pressure with elevation, the following notation is used:

P_1 = atmospheric pressure at reference elevation,
P_2 = atmospheric pressure at elevation to be measured,
$\Delta P = P_2 - P_1$,
V_0 = minimum volume of inner chamber,
V_1 = volume of inner chamber at reference elevation,
V_2 = volume of inner chamber at elevation to be measured,
$\Delta V = V_2 - V_1$,
N = counter number,
N_1 = counter number at reference elevation,

N_2 = counter number at elevation to be measured,
$\Delta N = N_2 - N_1$,
a = effective area of the bellows,
k = distance bellows moves per counter unit.

Since normal pressures and temperatures are employed, the atmosphere is very nearly an ideal gas and obeys the gas laws. As previously shown, the inner chamber is held at constant temperature, i.e., the gas is isothermal, and Boyle's Law can be applied. Thus,

$$P_1V_1 = P_2V_2,$$

and

$$P_1(V_2 - V_1) = -V_2(P_2 - P_1), \text{ an identity.}$$

$$\Delta V = -V_2\Delta P/P_1,$$

$$ak\Delta N = -(V_0 + akN_2)\Delta P/P_1,$$

whence

$$\Delta P/P_1 = -ak\Delta N/(V_0 + akN_2). \tag{1}$$

This means that by determining ΔN and N_2 and by using the known values of the constants a, k, and V_0 built into the instrument, we are able to measure the ratio of the change in pressure to total pressure. This ratio appears in the formula used in determining elevation difference between two points, which formula will now be discussed.

The hydrostatic equation relating pressure and altitude is

$$dP = -\rho g dh, \tag{2}$$

where P is the atmospheric pressure, ρ is the density of the atmosphere, g is the acceleration due to gravity, and h is the height. From the equation of state for ideal gases, we find ρ to be a function of P, or

$$\rho = Pm/RT,$$

where m is the gram molecular weight of air, R is the universal gas constant, and T is the temperature of the atmosphere.

Substituting this value into equation (2) and integrating between the limits P_1, P_2 and h_1, h_2, the equation becomes

$$\int_{h_1}^{h_2} dh = -RT/mg \int_{P_1}^{P_2} dP/P.$$

$$h_2 - h_1 = -(RT/mg) \log P_2/P_1. \tag{3}$$

In the foregoing, the factor RT/mg has been treated as a constant. R is a constant for ideal gases and may be considered as a constant for the gases making up the atmosphere, especially so since the total pressure involved will always be in the neighborhood of one atmosphere.

For T to be considered a constant means that the layer of atmosphere in which measurements are made is isothermal. This is seldom, if ever, true. Normally the temperature of an air column decreases at a rate of 0.6°C./100 m, but variations from this rate are frequent, especially near the earth's surface. In practice, it is customary to measure T_1 at the reference elevation and T_2 at the elevation to be measured and consider $(T_1+T_2)/2$ as the temperature of the air column. Even with this refinement, the temperature remains one of the most difficult factors to determine accurately.

The value of m, the gram molecular weight of air, is not constant. This is true because air contains water vapor, a component that varies widely in concentration. For dry air the proportions of the gases in the mixture vary but little. By taking a weighted mean of the gram molecular weights of the gases in the dry air mixture, a value for m_d, the "molecular weight" of dry air, may be determined. The value generally accepted for m_d is 28.9, and for m_w, the gram molecular weight of water vapor, the value is 18. From these values it follows that $m_w = 0.623\ m_d$. By defining the specific humidity (q) as $\rho_w/(\rho_d+\rho_w)$, where ρ_d is the density of dry air and ρ_w is the density of water vapor in a given mixture of moist air, it can be shown that the expression $m_d/(1+0.6q)$ is the correct expression for m in the factor RT/mg. Psychrometer readings made in the field during the survey supply data for obtaining values for q.

The value of g varies about 3 parts in 10,000 for an elevation change from 0 to 1,000 meters. Therefore, when a survey is to be made in a given area, an approximate mean value for g is selected for the area and no further corrections made for change in gravity.

If the difference in elevation, h_2-h_1, is denoted by Δh, the equation for elevation difference now becomes

$$\Delta h = -(R/m_d g)(1 + 0.6q)1/2(T_1 + T_2) \log P_2/P_1. \tag{4}$$

The term $\log P_2/P_1$ may be written as $\log (1+\Delta P/P1)$ and calculated to any degree of accuracy by expanding in a power series. Thus:

$$\Delta h = -(R/m_d g)(1 + 0.6q)1/2(T_1 + T_2)\left[(\Delta P/P_1) - 1/2(\Delta P/P_1)^2 + 1/3(\Delta P/P_1)^3 - 1/4(\Delta P/P_1)^4 + \cdots\right]. \tag{5}$$

Since $\Delta P/P_1$ is small in comparison to 1 for small differences in elevation, the above expansion for $\log (1+\Delta P/P_1)$ is a rapidly converging series, and the terms past the first in the expression may be neglected. When Δh is 100 feet, the error in neglecting the terms past $\Delta P/P_1$ is 0.15 feet. When Δh is 500 feet, the error is 4.7 feet.

Since $\Delta P/P_1$ may be expressed in terms of the constants of the instrument by equation (1), the expression for elevation difference may be written as:

$$\Delta h = (R/m_d g)(1 + 0.6q)1/2(T_1 + T_2)[ak\Delta N/(V_0 + akN_2)]. \quad (6)$$

The above expression for Δh, in which only the first term of the expansion appears, is desirable since the calculations are considerably simplified.

The expression (V_0+akN_2) is the volume of the inner chamber, V_2, at the elevation to be measured, h_2. It can be shown that the use of the average volume, $1/2(V_1+V_2)$, which may also be written as $V_0+1/2\ ak(N_1+N_2)$, instead of V_2 in equation (6) is essentially equivalent to using the first three terms of the original expansion. The accuracy of the elevation equation is thereby increased without complicating computation. The equation may now be written in its final form as:

$$\Delta h = (R/m_d g)(1 + 0.6q)1/2(T_1 + T_2)ak\Delta N/[V_0 + 1/2ak(N_1 + N_2)]. \quad (7)$$

In terms of elevation error, the equation is now correct to 0.01 feet in 100 feet, and 0.15 feet in 500 feet.

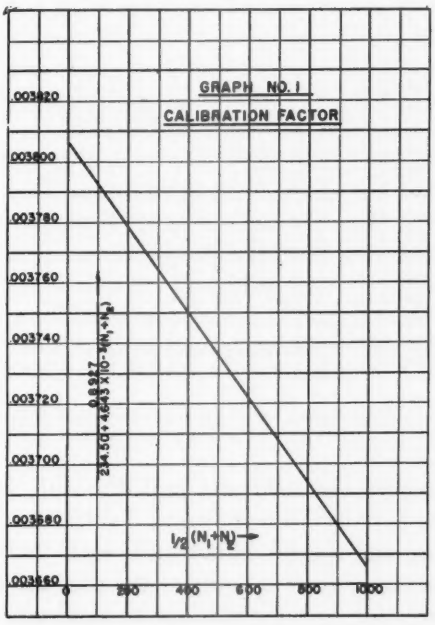

FIG. 4. Graph No. 1. Calibration Factor.

Figure 4 is a graph obtained by assigning the known values to the constants in the expression

$$(R/m_d g)ak/[V_0 + 1/2ak(N_1 + N_2)],$$

allowing N_1 and N_2 to vary from 0 to 1,000 (the range of the scale on the instrument), and plotting the resulting values as ordinates against $1/2(N_1+N_2)$ as abscissa. This curve is a conic, but because V_0 is large in comparison to $1/2\ ak \cdot (N_1+N_2)$, a straight line results.

For this instrument:

$$ak = 9.286 \times 10^{-3}\ cm^3,$$
$$V_0 = 234.500\ cm^3,$$
$$R/m_d = 2.8697 \times 10^6\ cm^2/\text{sec}^2 \text{ degree},$$
$$g = 979.228\ cm/\text{sec}^2 \text{ (at Dallas, Texas)}.$$

Therefore,

$$\Delta h = 0.2721(1+0.6q)1/2(T_1+T_2)\Delta N/[234.500+4.643\times 10^{-3}\ (N_1+N_2)] \text{ meters;}$$

or

$$\Delta h = 0.8927(1+0.6q)1/2(T_1+T_2)\Delta N/[234.500+4.643\times 10^{-3}\ (N_1+N_2)] \text{ feet.}$$

Figure 5 is a graph on which the-values of the factor $(1+0.6q)$ are plotted against vapor pressure at standard atmospheric pressure. Vapor pressure is used

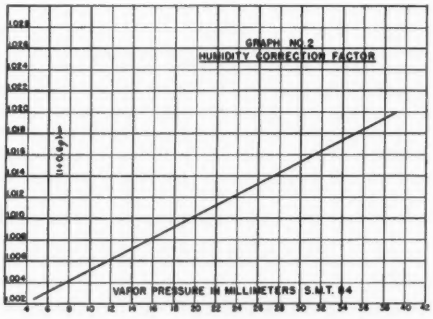

FIG. 5. Graph No. 2. Humidity correction factor.

as an abscissa of the curve since the wet and dry-bulb temperatures are easily converted to vapor pressure by Meteorological Tables.[3] Further, the relationship between vapor pressure and specific humidity is such that a straight line graph results. This graph is exactly accurate only at the pressure for which it was plotted. However the correction to the graph due to atmospheric pressure variation is small; and since the graph itself represents a correction to the elevation measurement that seldom exceeds one percent, the correction to the graph due to the variation in atmospheric pressure may be neglected. This is especially true in

[3] See *Smithsonian Meteorological Tables*, Publication 3116, the Smithsonian Institution, Washington, D. C., 1939, pp. 195–199.

view of the difficulty encountered in obtaining accurate temperature measurements in the field.

Where a more precise humidity correction is justified, the expression

$$0.6q = 0.378\ e/P$$

may be used, where e is the vapor pressure, and P is the atmospheric pressure. Values for $0.378\ e/P$ may be found in Table 60, Smithsonian Meteorological Tables.[4]

Experiments have shown that the value of e tends to remain constant for considerable altitude. This means that the psychrometer readings determining humidity may be made at any convenient point without appreciable error.

FIELD TECHNIQUE

In addition to the limitations already mentioned, the formula for elevation difference assumes certain conditions which cannot be met in the field. For example, it is assumed that readings are made simultaneously in a vertical column.[5] It is obvious that this cannot be done in the field.

Since the readings are necessarily displaced from the vertical, the troublesome atmospheric pressure fluctuations are encountered. Analysis of barograph records will show diurnal curves which are the result of the combination of many sine curves of different frequencies, amplitudes, and phase relations. In order to minimize the error introduced by this effect, two meters were used in the survey with the operators in communication by radiotelephone. Simultaneous readings were taken until the trends of the readings were very nearly the same. Thus, if both meters were increasing slowly, or decreasing slowly, or remaining nearly constant, it was assumed that each was being influenced by the same pressure field; provided, of course, that the horizontal separation between them was small, say one-half mile or less. Under ideal conditions where atmospheric pressure fluctuations are small, the horizontal separation between instruments may be increased to four or five miles.

Another source of trouble is the existence of vertical air currents and of eddy currents caused by horizontal winds blowing over rough terrain. The operator in the field will be able to detect these conditions and should discontinue the survey when they are severe. Obviously, the survey can not be made during thunderstorms and similar conditions of instability. Good data are often obtained at night when thermal gradients level off.

In the tests made at Dallas the "leap-frog" method of surveying was used. This method requires that two instruments be read side by side at the base station. This establishes the scale difference between the instruments at the start

[4] *Ibid.*, pp. 148–149.

[5] For further discussion of the formula and its application see Brombacher, W. G., "Altitude by measurement of Air Pressure and Temperature," *Journal of the Washington Academy of Sciences*, 34, No. 9 (September 15, 1944), 277–298.

of the survey. In the course of the survey the instruments are brought together at selected field stations to determine the amount of drift or change in this scale difference. At the end of the survey a drift curve plotting scale difference against time is used to determine the correction factor to be applied to readings of one instrument.

As soon as the base station readings are obtained, one instrument is moved up to the first field station, the other remaining at the base. Simultaneous readings are made until the trend in readings is the same for both.

When readings at the base and first field station are completed, the instrument at the base moves to the second field station, the instrument at the first field station remaining fixed. Simultaneous readings are again made until the trend is the same for both instruments. The instrument at the first field station then proceeds to the third field station and so on until the survey is completed. About once an hour the instruments are brought together at one of the field stations to check drift.

Temperature readings with a sling psychrometer are made at each station. These are used in the formula to make corrections for the variable density of air.

This method of conducting the survey has the advantage of keeping the instruments close together where their readings are influenced more nearly by the same atmospheric pressure field. Errors made in elevation differences between stations will be cumulative in the survey as a whole.

A second method of conducting a survey has been described by Kissam.[6] In order to use this method, two bases of known elevation, preferably above and below the range of the field stations, must be established in the area to be surveyed. Instruments located at these bases are read simultaneously with a third instrument located at the field station. By subtracting the elevation of the lower base from the elevation of the upper base, the actual elevation difference may be obtained. By subtracting the instrument reading at the lower base from the instrument reading at the upper base, the indicated elevation difference may be obtained. The ratio of the actual elevation difference to the indicated elevation difference may be used as a factor for converting scale units to elevation units. Thus, the indicated elevation difference between the field station and either one of the two bases becomes actual elevation difference when multiplied by this conversion factor.

In computing the elevation of the field station, it is good practice to determine the altitude differences between the field station and each of the bases as a check on the accuracy of the computations.

Since the conversion factor is inversely proportional to the density of the air at the time of the observation, no further correction is required for air density variation. The troublesome measurements of temperature and humidity are not necessary, a fact which is the strongest point in favor of this method. The two-

[6] Kissam, P., "Precision Altimetry," *Surveying and Mapping*, Vol. 5, No. 1 (January, 1945).

base method is essentially one in which a continuous calibration of pressure versus elevation is maintained by the two base stations. It is therefore required that the two bases be at different elevations.

The leap-frog method has an economic advantage over the two-base method in that only two instruments are required for the survey. In the two-base method three instruments are required, only one of which is making field measurements.

A TYPICAL SURVEY, MAY 14, 1948

A typical leap-frog survey was made on the morning of May 14, 1948. The sky was almost clear with a few alto-cumulus and fair weather cumulus clouds. The wind speed was fifteen miles per hour. This wind speed is approaching the value beyond which accurate barometric surveys are no longer possible because of the erratic pressure fluctuations associated with the eddy currents set up in brisk winds.

The instruments were read together at stations one, six, and again at one. From these readings the drift curve, Figure 6, was drawn. Values for drift curve corrections at the various observation times are read from this curve.

TABLE I

SUMMARY SHEET

Station	Transit Elevations (Feet)	Elevation Meter	Elevation Difference Error	Elevation Error
1	700.20	700.2		
	− 25.13	− 24.3	−0.8	
2	675.07	675.9		+0.8
	−115.81	−116.7	+0.9	
3	559.26	559.2		−0.1
	− 27.53	− 28.4	+0.9	
4	531.73	530.8		−0.9
	− 44.57	− 44.2	−0.4	
5	487.16	486.6		−0.6
	− 10.95	− 11.9	+0.9	
6	476.21	474.7		−1.5
	+ 8.42	+ 8.9	+0.5	
7	484.63	483.6		−1.0
	− 23.13	− 24.3	+1.2	
8	461.50	459.3		−2.2
	− 2.94	− 2.4	−0.5	
9	458.56	456.9		−1.7
	+ 14.37	+ 13.6	−0.7	
10	472.93	470.5		−2.4
	+ 64.29	+ 65.2	+0.9	
11	537.22	535.7		−1.5
	+ 78.53	+ 79.1	+0.6	
12	615.75	614.8		−1.0
	+ 61.87	+ 62.6	+0.7	
13	677.62	677.4		−0.2
	+ 22.58	+ 21.6	−1.0	
1	700.20	699.0		−1.2
		Average	0.8	1.2
		Maximum	1.2	2.4

The survey consisted of a loop of thirteen stations from one-quarter to three-quarters of a mile apart located in rolling terrain. A survey with a transit was made to serve as a basis for determining the accuracy of the barometric survey. The summary sheet, Table 1, shows the comparison between the elevation values for the stations as obtained by the two surveys. Assuming the transit elevations

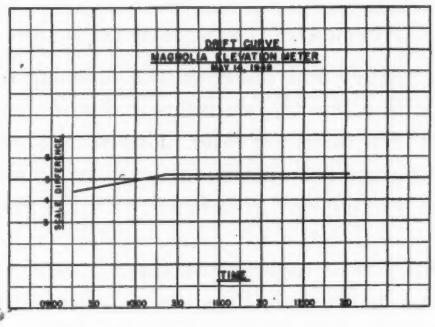

FIG. 6. Drift curve. Magnolia elevation meter. May 14, 1948.

TABLE 2

ELEVATION SURVEY COMPUTATION SHEET

May 14, 1948	Sta	Reading	Sta	Reading	Sta	Reading	Sta	Reading	Sta	Reading	Sta	Reading
(A) Time		0923		0935		0947		1000		1010		1040
(B) Instrument No. 1	1	430.6	3	307.1	3	311.9	5	251.6	5	253.6	7	259.5
(C) Drift Curve Correction		4.5		4.6		4.9		4.9		5.1		5.2
(D) $B-C$		426.1		302.5		307.0		246.7		248.5		254.3
(E) Instrument No. 2	2	404.5	2	405.9	4	281.9	4	285.6	6	238.0	6	246.5
(F) $/D-E/=/\Delta N/$		−21.6		−103.4		−25.1		−38.9		−10.5		+7.8
(G) Graph No. 1		.003747		.003756		.003765		.003769		.003772		.003771
(H) $(t_d-t_w)t_w$(°C)		3.3/21.4		3.3/21.4		3.8/20.9		3.8/21.4		3.8/21.4		5.0/21.9
(I) Vapor Pres. (mm)(SMT 84)		17.44		17.44		16.04		17.12		17.12		17.15
(J) Graph No. 2 ($1+0.6q$)		1.0088		1.0088		1.0081		1.0086		1.0086		1.0087
(K) $1/2(T_1+T_2)$(°K)		297.9		297.9		297.9		298.4		298.4		300.1
(L) $F\times G\times J\times K$ Elevation (Ft)		−24.3		−116.7		−28.4		−44.2		−11.9		+8.9

May 14, 1948	Sta	Reading	Sta	Reading	Sta	Reading	Sta	Reading	Sta	Reading	Sta	Reading	Sta	Reading
(A) Time		1059		1115		1135		1150		1203		1215		1230
(B) Instrument No. 1	7	260.0	9	240.0	9	241.9	11	314.6	11	317.5	13	443.6	13	447.4
(C) Drift Curve Correction		5.2		5.2		5.2		5.2		5.2		5.2		5.2
(D) $B-C$		254.8		234.8		236.7		309.4		312.3		438.4		442.2
(E) Instrument No. 2	8	233.5	8	236.9	10	248.6	10	252.4	12	381.7	12	383.6	1	461.1
(F) $/D-E/=/\Delta N/$		−21.3		− 2.1		+11.9		+57.0		+69.4		+54.8		+18.9
(G) Graph No. 1		.003772		.003773		.003772		.003767		.003757		.003748		.003742
(H) $(t_d-t_w)t_w$(°C)		5.0/21.9		5.2/22.8		5.1/22.8		4.4/23.0		4.4/23.0		4.7/23.8		4.7/23.8
(I) Vapor Pres. (mm)(SMT 84)		17.15		18.36		18.36		18.84		18.84		19.72		19.72
(J) Graph No. 2 ($1+0.6q$)		1.0087		1.0092		1.0092		1.0096		1.0096		1.0099		1.0099
(K) $1/2(T_1+T_2)$(°K)		300.1		301.2		301.2		300.6		300.6		301.7		301.7
(L) $F\times G\times J\times K$ Elevation (Ft.)		−24.3		− 2.4		+13.6		+65.2		+79.1		+62.6		+21.6

If Instrument No. 1 moves, ΔN is positive when $D>E$ and ΔN is negative when $D<E$.
If Instrument No. 2 moves, ΔN is positive when $D<E$ and ΔN is negative when $D>E$.

to be correct, the elevation meter made an average error of 0.8 foot in thirteen difference measurements, with a maximum error of 1.2 feet. The cumulative or closure error in the usrvey amounted to 1.2 feet with 2.4 feet the maximum and 1.2 feet the average.

The computation sheet, Table 2, is included for information. Values for (B) and (E) are taken directly from the operators data sheet and are based on the judgment of the computer as to what values best represent simultaneous readings. Column (H) is the record of psychrometer readings, t_d being dry-bulb and t_w wet-bulb temperature.

A SUBSTITUTION METHOD FOR THE ABSOLUTE CALIBRATION OF VIBRATION PICK-UPS*

NORMAN A. HASKELL†

ABSTRACT

By making use of the general relations between input and output currents and voltages in four-terminal networks of bilateral impedances a relationship is derived between the velocity response of a reversible vibration pick-up and the velocity output of the same device, when used as a source of mechanical vibrations. It is then shown that any vibration pick-up may be calibrated in absolute terms as a function of frequency by purely electrical measurements (input current and output voltage) made on the given pick-up, an auxiliary reversible pick-up, and a variable frequency driver.

In connection with acoustic measurements in fluid media, it is well known that the response of a microphone as a function of frequency can be determined in terms of absolute sound intensity without the use of a primary standard. The method involves purely electrical measurements made on the given microphone a second auxiliary microphone, and a source of sound of variable frequency, none of whose calibrations need be known in advance.[1] The microphone to be calibrated may be of any type, but the auxiliary microphone must be a reversible device. It is, perhaps, obvious that a similar method of calibration should be possible for electro-mechanical devices intended to measure the vibrations of a solid medium, but no explicit statement of the relationships in this case has come to the writer's attention. The method is particularly convenient for calibration at frequencies that are too high to be readily generated with sufficient amplitude to be measured by direct optical means. As in the microphone case, a source of vibrations of variable frequency and an auxiliary reversible pick-up are required, in addition to the pick-up to be calibrated.

We shall use subscripts p, a, and d to designate quantities referring to the given pick-up, the reversible auxiliary pick-up, and the mechanical driver of variable frequency respectively, and let

$R(\omega)$ = pick-up response expressed as open-circuit voltage output per unit velocity amplitude of the vibrations impressed on the case, or point of attachment, of the pick-up,

$S(\omega)$ = velocity output of a driver, under no mechanical load, per unit current input,

Z^{mo} = mechanical input impedance with electrical terminals open,

Z^{ms} = mechanical input impedance with electrical terminals short circuited,

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[1] W. R. McLean, Absolute Measurement of Sound Intensity Without a Primary Standard, *Jour. Acoust. Soc. Am.* 12, (1940), 140.

Z^{eo} = electrical input impedance with mechanical end attached to an infinite mechanical impedance (equivalent to electrical open circuit),

Z^{es} = electrical input impedance with mechanical end free (equivalent to electrical short circuit),

M = mass,

ω = radian frequency.

It will be first shown that, for any reversible pick-up, R and S are connected by the relation

$$R/S = Z^{mo}. \tag{1}$$

To prove this relation, consider two identical units of this kind to be fastened base to base, and let V be the open-circuit voltage output of one when a current I is

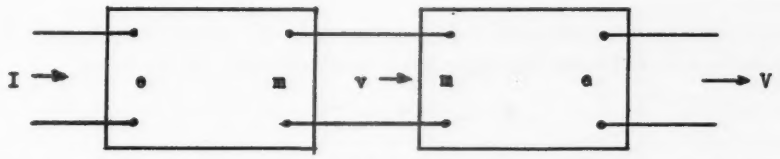

FIG. 1. Electrical analog of a reversible pick-up driving an identical reproduction of itself.

supplied to the other. If we conceive the mechanical parts of each to be replaced by their electrical analogs,[2] the system may be represented as indicated in Figure 1, where the two four-terminal networks are to be considered as identical, and the current flowing between them is taken as numerically equal to the velocity, v, that the unit used as a driver impresses on the one used as a pick-up.

By definition, $R = V/v$, and from the general relations that hold for arbitrary four-terminal networks of bilateral impedances we have

$$V/v = [Z^{eo}(Z^{mo} - Z^{me})]^{1/2}. \tag{2}$$

Furthermore, S is the ratio v/I that is obtained when the pick-up network is replaced by a short circuit. For this case we have

$$S = [(Z^{eo} - Z^{es})/Z^{mo}]^{1/2}. \tag{3}$$

[2] It has been shown by E. M. McMillan, *Jour. Acoust. Soc. Am.* 18, (1946), 344, that when the electromechanical coupling is electrostatic or piezoelectric, the mutual impedance Z_{ab} representing the coupling is bilateral, i.e., $Z_{ab} = Z_{ab}$, and the reciprocity theorem is satisfied. When the coupling is magnetic, $Z_{ab} = -Z_{ab}$, a situation to which McMillan applies the term "antireciprocity." In an antireciprocal system the relations between input and output currents and voltages are the same in magnitude as in a reciprocal system, and differ only by a constant phase factor. Two antireciprocal systems in tandem are equivalent to a reciprocal system, so that in the derivation of equation (1) it is immaterial which type is assumed. McMillan shows, however, that reciprocal and antireciprocal systems can be combined in such a way as to violate reciprocity in magnitude as well as in phase.

By combining equations (2) and (3),

$$R/S = Z^{mo}[Z^{eo}(Z^{mo} - Z^{ms})/Z^{mo}(Z^{eo} - Z^{es})]^{1/2}$$

from which equation (1) follows immediately, since the expression in brackets reduces to unity by virtue of the relation, $Z^{eo}Z^{ms} = Z^{mo}Z^{es}$.

If the pick-up to be calibrated is itself a reversible device, and if two such units may be considered to be identical within the desired accuracy of the calibration, the auxiliary pick-up and driver are unnecessary, since the calibration may be obtained by measuring the input current, I, and open circuit output voltage, V, when one unit is used to drive the other. The velocity output of the driver, when working into a mechanical impedance Z is given by

$$v/I = [Z_p{}^{mo}(Z_p{}^{eo} - Z_p{}^{es})]^{1/2}/(Z_p{}^{mo} + Z) = S_p/(1 + Z/Z_p{}^{mo}). \quad (4)$$

In the case under consideration $Z = Z_p{}^{mo}$, hence $v/I = S_p/2$, and $R_p = V/v = 2V/ISp$. By eliminating S_p between this expression and equation (1) we have

$$R_p{}^2 = 2VZ_p{}^{mo}/I. \quad (5)$$

If the sprung mass in the pick-up is small compared to the mass that may be considered to move as a rigid body within the range of frequencies employed, and if its motion is well damped, the mechanical impedance of the pick-up is $j\omega M_p$, and equation (5) becomes

$$R_p{}^2 = 2j\omega M_p V/I. \quad (6)$$

If R_p, V, and I are expressed in practical electrical units, the right hand side of this equation is to be multiplied by 10^{-7} when M is in grams and the vibration velocity is in centimeters per second.

In the general case, in which it is not assumed that the pick-up is reversible, or that an identical reproduction is available, the procedure is as follows. With the pick-up mounted on the variable frequency driver, measure the open-circuit output voltage, V_{pd}, as a function of frequency for constant (or measured) current input to the driver. Substitute the auxiliary pick-up and measure its open-circuit output voltage, V_{ad}, for the same current input to the driver. Since the velocity impressed on the pick-up is proportional to $S_d/(1+Z^{mo}/Z_d{}^{mo})$,

$$V_{ad}/V_{pd} = R_a(1 + Z_p{}^{mo}/Z_d{}^{mo})/R_p(1 + Z_a{}^{mo}/Z_d{}^{mo}). \quad (7)$$

If the reversible auxiliary is now used as a driver for the given pick-up, the input current, I_{pa} and output voltage, V_{pa}, are connected by the relation

$$V_{pa} = I_{pa}S_aR_p/(1 + Z_p{}^{mo}/Z_a{}^{mo}). \quad (8)$$

Elimination of R_a and S_a between equations (7), (8), and (1) yields

$$R_p{}^2 = V_{pa}V_{pd}(Z_a{}^{mo} + Z_p{}^{mo})(Z_p{}^{mo} + Z_d{}^{mo})/V_{ad}I_{pa}(Z_a{}^{mo} + Z_d{}^{mo}). \quad (9)$$

If the construction of the driver and both pick-ups is such that $Z^{mo}=j\omega M$ in each case, equation (9) becomes

$$R_p^2 = j\omega V_{pa}V_{pd}(M_a + M_p)(M_p + M_d)/V_{ad}I_{pa}(M_a + M_d). \qquad (10)$$

If the pick-up to be calibrated is not of a type in which the moving mass is negligible compared to the rigid mass, equation (9) may still be used for calibration without detailed knowledge of the elastic properties and damping of the various units, provided the auxiliary pick-up is so constructed as to fulfill this condition and, further, that $\left|Z_d^{mo}\right| \gg \omega M_a \gg \left|Z_p^{mo}\right|$. In this case equation (9) becomes

$$R_p^2 = j\omega M_a V_{pa} V_{pd}/V_{ad} I_{pa}. \qquad (11)$$

When R_p has been computed from equation (10) or (11), R_a may be determined from equation (7), and S_a is then known from equation (1). Also, knowing R_p, V_{pd}, and the current supplied to the driver, the driver output function, S_p may be computed. Thus, as a by-product of the calibration, the auxiliary pick-up and the driver are also calibrated. If the same driver and auxiliary are used to calibrate a number of pick-ups, and all calibrations are computed independently in each case, the consistency of the driver and auxiliary calibrations will serve to indicate the degree to which the assumptions of reversibility and the relative magnitudes of the mechanical impedances have actually been fulfilled.

PATENTS*

4—ACCELEROMETER

U. S. No. 2,472,829. W. H. Hoppmann. Iss. 6/14/49. App. 8/11/45.

Peak Accelerometer. A peak accelerometer having an inertia weight held by a frangible material with a small neck which breaks if the acceleration exceeds a predetermined limit.

U. S. No. 2,474,610. E. P. Wunsch. Iss. 6/28/49. App. 5/29/45.

Quantitative Deceleration Indicator. An automobile stop light control having a spring-supported mass arranged to actuate switches which turn on more lamps so as to increase the stop light illumination as the deceleration increases.

12—ACOUSTIC MEASUREMENTS

U. S. No. 2,468,537 & 8. H. Benioff. Iss. 4/26/49. App. 7/23/45 and 1/10/46. Assign. Submarine Signal Co.

Ultra High Frequency Vibrator. A piezoelectric ultrasonic vibrator whose crystal has one side free and the other side in contact with a liquid into which may be immersed another container with a thin diaphragm and containing material to be vibrated.

U. S. No. 2,469,282. R. W. Stanmyre. Iss. 5/3/49. App. 10/26/46.

Device for Indicating the Sum of the Intensity and Duration of Sound. A sound impulse meter having a microphone whose output is amplified, rectified and drives an electric motor which is geared to rotate a pointer.

U. S. No. 2,470,114. R. M. Sherwood, R. J. Urick and L. P. Delsasso. Iss. 5/17/49. App. 7/12/46.

Optical Sound Bearing System. A sound-ranging system using three receiving stations and in which the time differences between their respective signals are determined on a c-r oscilloscope.

16—AIRPLANE FLIGHT INSTRUMENTS

U. S. No. 2,467,179. J. H. Andresen, Jr. Iss. 4/12/49. App. 3/30/45. Assign. Square D Co.

Automatic Position Indicator. An aircraft position indicator in which the signal from a true airspeed indicator is fed into a compass indicator and resolved into sine and cosine signals which actuate latitude and longitude counters through thyratron tubes.

U. S. No. 2,467,412. R. L. Wathen. Iss. 4/19/49. App. 6/9/44. Assign. The Sperry Corp.

Navigation Instrument. A course indicator which shows the position of the aircraft with respect to a radio glide path and also with respect to the ground.

U. S. No. 2,467,972. R. W. French. Iss. 4/19/49. App. 4/19/47.

Combined Beam Indicator, Compass, and Gyro-Horizon for Aircraft. A single blind-landing instrument which gives on one dial simultaneous indications of compass direction, gyro-horizon and radio beam readings.

U. S. No. 2,469,571. O. V. Phillips. Iss. 5/10/49. App. 11/2/45.

Flight Position Indicator for Aircraft. An aircraft attitude indicator having a gimbal-mounted pendulous housing with a heavy ball which rolls on a spherical surface and an indicator connected to the housing.

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation.

U. S. No. 2,474,537. J. A. MacLeod. Iss. 6/28/49. App. 3/29/46. Assign. Sun Chemical Corp.

Position Indicator for Aircraft. A device for releasing water-marking material in the event of a crash landing on water.

U. S. No. 2,474,618. R. L. Divoll. Iss. 6/28/49. App. 4/8/46. Assign. Bendix Aviation Corp.

Altitude Control. A device for maintaining an aircraft at a preset altitude and having a sealed chamber with a diaphragm whose deflections displace the exciting winding of a balanced pair of opposed secondaries whose output is amplified and used to drive elevator-control motors.

24—BAROMETER

U. S. No. 2,473,610. F. Rieber. Iss. 6/21/49. App. 1/29/44. Assign. Interval Instruments, Inc.

Barometer. A barometer having a sealed capsule with a diaphragm which changes the tension on a wire kept in sustained oscillation in the field of a magnet by a vacuum-tube oscillator whose frequency is indicated.

40—CABLE

U. S. Re. 23,099. (Orig. No. 2,395,302) J. J. Slomer. Iss. 4/12/49. App. 5/12/44, 2/19/46 and 9/30/48. Assign. Goodman Manufacturing Co.

Cable Reel. A cable reel which is driven by a hydraulic motor and pumps with automatic valves so as to maintain constant tension on the cable when paying out or reeling in.

U. S. No. 2,467,238. J. J. Slomer. Iss. 4/12/49. App. 5/1/46. Assign. Goodman Manufacturing Co.

Fluid Pressure Cable Reel Drive. A cable reel which is driven by a hydraulic motor actuated by two pumps, one pump being driven from power derived through the cable and the other from power derived from motion of the vehicle.

U. S. No. 2,472,860. J. D. Russell. Iss. 6/14/49. App. 9/2/44. Assign. Joy Manufacturing Co.

Combined Cable Guide Arm and Torque Control Switch. A cable reel with a hinged arm over which the cable passes and arranged to operate a switch in the reel-motor drive when the cable direction changes so as to prevent straining the cable.

U. S. No. 2,473,071. C. R. Pieper. Iss. 6/14/49. App. 7/9/47.

Cable Clamping Device. A cable clamp in which the cable is taken around the outside of a grooved disc starting at the bottom and the end clamped at the center.

68—COMPUTING DEVICES

U. S. No. 2,467,646. G. Agins. Iss. 4/19/49. App. 7/18/40 and 12/6/46. Assign. Arma Corp.

Computer Apparatus. A trigonometric computer having an induction regulator which may be set to the proper angle and an inverse feedback amplifier between the rotor and stator.

U. S. No. 2,468,150. D. E. Wilcox. Iss. 4/26/49. App. 11/6/45. Assign. Consolidated Engineering Corp.

Computer. A simultaneous equation computer for manual operation by the iterative method in which convergence of stubborn systems is obtained by introducing an auxiliary voltage which is the product of quantities related to the coefficients of the equations.

U. S. No. 2,469,627. J. R. Bowman. Iss. 5/10/49. App. 3/19/43. Assign. Gulf Research & Development Co.

Calculating Machine for Solving Simultaneous Equations. An electrical simultaneous equation solver in which the residual signal from each equation network is applied to the input of an amplifier whose output controls current-supplies feeding current representing the unknowns into the network.

U. S. No. 2, 469,628. J. R. Bowman and R. T. Steinback. Iss. 5/10/49. App. 4/27/45. Assign. Gulf Research & Development Co.

Calculating Machine. An electrical simultaneous equation solver in which the residual signal from each equation network is applied to the input of an amplifier whose output controls rectifiers which rectify a-c from a separate source to give d-c representing the unknown which is fed into the network.

U. S. No. 2,471,788. R. L. Snyder, Jr. and J. A. Rajchman. Iss. 5/31/49. App. 3/31/42 and 2/15/47. Assign. Radio Corp. of America.

Electronic Computer. A device for computing a function of the angle between two movable semi-circular masks between which is interposed a transparent scale by passing light through the masks and scale and a rotating radial slit and counting the light pulses or indicating their frequency.

U. S. No. 2,472,464. W. A. Bruce. Iss. 6/7/49. App. 4/19/45. Assign. Standard Oil Development Co.

Well Analyzer. An electrical analogue circuit in which the source of power represents formation pressure, current represents production rate, and other formation and well factors are represented by condensers and resistors so that the effect of changes may be easily observed.

92—DRILL

U. S. No. 2,472,359. H. J. Woolslayer, C. Jenkins and W. H. Luttgen. Iss. 6/7/49. App. 4/20/48. Assign. Lee C. Moore Corp.

Oil Well Drilling Apparatus Having Crown Block Movable Lengthwise of Mast. A collapsible drilling mast which is hinged to the substructure and which has a track by which the crown block may be moved onto the substructure when the mast is in a horizontal position.

U. S. No. 2,472,999. E. L. Alexander and A. W. Braithwaite. Iss. 6/14/49. App. 6/4/45. Assign. The George E. Failing Supply Co.

Portable Drilling Rig. A skid-mounted portable drilling rig having the ring gear and kelly drive mounted on a swivel to permit drilling at various angles and a hinge on the swivel to permit moving the drill-rotating mechanism out of the way when running pipe.

104—EARTH AUGER

U. S. No. 2,472,120. I. R. Murphy. Iss. 6/7/49. App. 12/6/44.

Explosively Actuated Tool. An earth-boring tool having a pointed drive rod with an enlarged cup at the top in which a tamped explosive may be detonated to drive the tool into the ground.

108—ECHO SOUNDING

U. S. No. 2,465,990. A. E. Anderson. Iss. 4/5/49. App. 7/8/44. Assign. Submarine Signal Co.

Distance Measuring Device. An echo-sounding apparatus using a neon lamp rotating adjacent to a circular scale for visual indication and connected in series with a recording stylus which rotates across a record tape, the stylus rotating at a slower speed and short circuited when the stylus is off the tape.

U. S. No. 2,473,974. O. H. Schuck. Iss. 6/21/49. App. 5/18/44. Assign. U. S. A.

Underwater Sound Detecting and Indicating System. An echo sounding or ranging system in which an omnidirectional transmitter periodically emits pulses during a time interval and reflections are picked up by a directional receiver which rotates one revolution during the same interval and the received signals are indicated on a synchronously-sweeping c-r tube trace.

116—ELECTRIC LOGGING

U. S. No. 2,469,383. C. J. Gibbs and J. H. Stein. Iss. 5/10/49. App. 3/4/44. Assign. Texaco Development Corp.

Method and Apparatus for Removing Random Fluctuations from Intensity Measurements. An arrangement for smoothing out random fluctuations in a well-logging indicator by an R-C circuit, the resistance being shunted by biased diodes so that when large indications are received the time constant is reduced.

U. S. No. 2,473,713. B. M. Kingston and M. H. McKinsey. Iss. 6/21/49. App. 5/20/46. Assign. one-half to Shell Development Co. and one-half to The Independent-Eastern Torpedo Co.

Well Fluid Measurement. A device for following a water-oil interface in a well and in which the water between electrodes completes the primary circuit of one or more induction coils whose secondary voltages are detected at the surface.

124—ELECTRICAL PROSPECTING

U. S. No. 2,470,412. R. G. Piety. Iss. 5/17/49. App. 12/7/43. Assign. Phillips Petroleum Co.

Alternating Current Impedance Meter. An impedance meter for small impedances in which the a-c source supplies a constant current and triggers a square-wave oscillator whose output is added to the voltage across the impedance and the resultant voltage measured.

136—EXPLOSIVE

U. S. Re. 23,102. (Orig. No. 2,408,189). A. W. Baker. Iss. 4/26/49. App. 11/10/42, 9/24/46 and 8/21/47. Assign. Hercules Powder Co.

Waterproof Explosive Cartridge. A waterproof dynamite cartridge made up of several layers of waterproof paper with a disc at the end over which the paper is rolled or crimped and the end sealed with a semi-flexible compound.

U. S. No. 2,468,274. J. E. Riley. Iss. 4/26/49. App. 7/29/44. Assign. Hercules Powder Co.

Explosive Device. A sleeve for connecting dynamite cartridges end to end and having an explosive fuse spirally wound around it.

U. S. No. 2,470,082. A. T. Tyre. Iss. 5/10/49. App. 9/8/44 and 9/7/45. Assign. Imperial Chemical Industries Ltd.

Gas-Producing Charges Suitable for the Generation of Gas Pressure for the Operation of Mechanical Devices and for Blasting Operations. An explosive capable of progressive self-sustaining gas-producing decomposition containing nitroguanidine, guanidine nitrate or dicyandiamine nitrate together with sodium hypophosphite, calcium hypophosphite or ammonium hypophosphite.

U. S. No. 2,470,733. E. Whitworth and J. C. Hornel. Iss. 5/17/49. App. 3/14/45 and 1/29/46. Assign. Imperial Chemical Industries Ltd.

Stabilized Blasting Explosive Composition. A blasting explosive comprising a nitric ester, ammonium nitrate and a small amount of a mixture of a dialkali hydrogen ortho-phosphate and an alkali metal dihydrogen ortho-phosphate.

U. S. No. 2,471,381. J. Yurick and F. J. Yurick. Iss. 5/24/49. App. 10/4/46.

Safety Device for Blasting Caps. A mechanically strong cartridge containing a small amount of explosive into which a blasting cap may be placed so as to protect the cap while the charge is being tamped.

U. S. No. 2,473,405. D. T. Zebree. Iss. 6/14/49. App. 1/24/45. Assign. Hercules Powder Co.

Delay Electric Initiator. A delay-type electric blasting cap using in the matchhead a composition of primary explosive, oxidizing material, flash-producing material and a binding agent.

140—FLAW DETECTOR

U. S. No. 2,467,301. F. A. Firestone. Iss. 4/12/49. App. 7/23/45. Assign. Sperry Products, Inc.

Supersonic Inspection for Flaws Lying Near the Surface of a Part. A sonic inspection system in which a thick layer of transmitting material is placed between the crystal transceiver and the material under test so that flaws lying near its surface may be resolved.

U. S. No. 2,467,306. W. E. Habig. Iss. 4/12/49. App. 9/8/43. Assign. Sperry Products, Inc.

Flaw Detector for Tubing and the Like. A system for testing round stock for flaws by passing it through a multiphase rotating field and detecting unbalance in eddy currents generated in the material.

U. S. No. 2,467,328. W. E. Mesh. Iss. 4/12/49. App. 2/27/46. Assign. Sperry Products, Inc.

Rail Flaw Detector Mechanism. A flaw detector for railroad rails in which the detector becomes inoperative when a joint is reached and with a delay in the detecting coil cut-off so it may get as close to the joint as possible.

U. S. No. 2,470,341. W. C. Darrah. Iss. 5/17/49. App. 3/7/46. Assign. Raytheon Manufacturing Co.

Method of Flaw Detection. A method of detecting fissures by agitating the object in a mixture of powdered silica and powdered fluorescein, removing the excess powder, immersing in oil, removing the excess oil, and examining under ultra-violet light.

U. S. No. 2,472,784. W. C. Barnes and H. W. Keevil. Iss. 6/14/49. App. 9/8/43.

Method and Apparatus for Detecting Flaws. A magnetic rail-flaw detector having pickups on the gauge side of the rail and on top of the rail and arranged so that impulses due to wheel burns and gag marks temporarily reduce the sensitivity of the other pickup amplifiers.

144—FLOW LOGGING

U. S. No. 2,473,713. B. M. Kingston and M. H. McKinsey. Iss. 6/21/49. App. 5/20/46. Assign. one-half to Shell Development Co. and one-half to The Independent-Eastern Torpedo Co.

Well Fluid Measurement. A device for following a water-oil interface in a well and in which the water between electrodes completes the primary circuit of one or more induction coils whose secondary voltages are detected at the surface.

148—FLOW METER

U. S. No. 2,468,896. W. Rohn. Iss. 5/3/49. App. 4/15/40 and 4/28/41. Vested in the Attorney General of the U. S.

Instrument for Measuring and Indicating the Intensity of Gas Current. A gas flow meter in which a tapered plunger actuates a pointer and which automatically corrects the gas to standard conditions by a bimetallic strip which corrects for temperature by changing the pointer balance and a weighted bellows which corrects for pressure by changing the pointer balance.

U. S. No. 2,472,056. R. M. Otis. Iss. 5/31/49. App. 12/11/44. Assign. Lane-Wells Co.

Flowmeter. A mass flow meter having a disc in a tapered throat through which the liquid flows and also a float submerged in a tank of the liquid, with both the disc and the float mounted on a rod which moves an armature in an electromagnetic indicating system.

U. S. No. 2,473,765. V. G. Platts. Iss. 6/21/49. App. 11/20/44. Assign. Phillips Petroleum Co.

Liquid Flow Measuring Apparatus. A flow meter in which the liquid pours into a container with a series of vertically-spaced holes in its side on a balance arm with a chain counterweight, the balance point depending on the amount of liquid maintained in the container by the flow.

160—GALVANOMETER

U. S. No. 2,469,265. C. M. Hathaway. Iss. 5/3/49. App. 2/24/44.

Oscillograph. A moving-coil oscillograph unit having cylindrical pole pieces whose axis is at right angles to the suspension and to the light beam, so that tilting of the unit is accomplished by rotating the unit and its pole pieces in the field magnet which supports the unit.

164—GAMMA RAY LOGGING

U. S. No. 2,470,743. F. P. Hochgesang and C. H. Schlesman. Iss. 5/17/49. App. 9/16/44. Assign. Socony-Vacuum Oil Co., Inc.

Method and Apparatus for Geophysical Prospecting. A well logging apparatus which has a mechanical cutter to remove mud from the well wall and an X-ray tube whose output is directed through a window to the well wall and diffracted X-rays photographed.

168—GAS ANALYSIS

U. S. No. 2,467,211. A. J. Hornfeck. Iss. 4/12/49. App. 2/24/44. Assign. Bailey Meter Co.

Method of and Apparatus for Magnetically Determining Gas Content. A gas-analysis apparatus in which a non-conducting non-magnetic slotted disc is rotated in the gas in a magnetic field between pole pieces and the emf induced in coils about the pole pieces amplified and indicated.

U. S. No. 2,468,261. J. Hillier. Iss. 4/26/49. App. 8/7/47. Assign. Radio Corp. of America.

Gas Analyzer. A gas analyzing apparatus in which a monokinetic stream of electrons is impinged upon the gas under reduced pressure and the electrons then analyzed for their residual velocity distribution.

U. S. No. 2,472,645. W. J. Clark. Iss. 6/7/49. App. 10/11/44. and 9/20/45 Assign. Imperial Chemical Industries Ltd.

Thermal Conductivity Analysis of Gases. A katharometer in which the change of resistance of a heated wire in the gas is indicated by a bridge circuit and is corrected for gas pressure changes by a bellows moving an armature in an a-c induction balance whose output is rectified and fed to the incating bridge.

172—GEOCHEMICAL PROSPECTING

U. S. No. 2,470,401. L. Horvitz. Iss. 5/17/49. App. 2/33/39. Assign. E. E. Rosaire.

Exploration by Soil Analysis. A method of soil wax prospecting in which soil samples are treated successively with hydrochloric acid and an organic solvent.

188—HYGROMETER

U. S. No. 2,466,658. P. A. Hiltz. Iss. 4/5/49. App. 1/25/46. Assign. Serdex, Inc.

Hygrometric Device. A hygrometer having a spring-deflected diaphragm of hygroscopic goldbeater's skin mounted in a cylindrical casing with the deflection of the diaphragm indicated.

U. S. No. 2,466,696. F. A. Friswold and R. D. Lewis. Iss. 4/12/49. App. 9/25/45.

Dew Point Hygrometer. A dew-point hygrometer using a mirror thermally connected to a tank of coolant, heat being applied to the mirror until the condensed moisture is evaporated and with the mirror-heating current controlled by the light reflected from a lamp onto a photocell.

U. S. No. 2,466,903. A. R. Low and R. S. Segsworth. Iss. 4/12/49. App. 4/28/44. Assign. The General Engineering Co. (Canada) Ltd.

Electrical Hygrometer. An electrical hygrometer using a thin strip of electrically-conducting cellulosic material clamped between two contacts connected to a resistance-measuring instrument.

U. S. No. 2,467,316. J. Kahl. Iss. 4/12/49. App. 7/5/45.

Psychrometer. A holder for a wet and dry bulb thermometer and having a fan which circulates air and radiation shields on which the thermometers are mounted.

U. S. No. 2,468,691. D. B. Smith. Iss. 4/26/49. App. 5/30/44. Assign. Philco Corp.

Hygrometry. A dew-point hygrometer having a metal mirror from which light is reflected onto a photocell which controls the current through a thermocouple junction which cools the mirror.

U. S. No. 2,469,537. H. Wohrer. Iss. 5/10/49. App. 1/12/45. Assign. Johnson Service Co.

Humidostatic Element. A hygrometer element having a thin metal strip with negligible thermal expansion coated with a layer of gelatin whose linear expansion varies with humidity to cause bending of the strip.

196—INFRARED MEASUREMENTS

U. S. No. 2,473,197. J. Evans. Iss. 6/14/49. App. 6/21/45. Assign. Radio Corp. of America.

Heat Detecting System. An infrared detecting and amplifying system in which the heat detector signal is applied to the grid of an oscillator tube so as to change its frequency and the latter indicated.

200—LEVEL INDICATORS

U. S. No. 2,467,365. D. H. Annin. Iss. 4/19/49. App. 6/4/45. Assign. Grove Regulator Co.

Liquid Level Indicating Apparatus. A tank level indicator having a vertical tube connected to the tank with resilient pipe and with the weight of the tube actuating a pneumatic pilot valve to a pneumatic indicator.

U. S. No. 2,468,676. W. Liben. Iss. 4/26/49. App. 4/20/45. Assign. Premier Crystal Laboratories, Inc.

Level Indicating Device for Fluent Materials. A device for indicating when the level in a tank falls below a predetermined level by ha ing at the level a heating element adjacent to a bimetallic temperature indicator which indicates the temperature change when the ambient material surrounding the heater changes.

U. S. No. 2,472,249. C. A. de Giers and A. Edelman. Iss. 6/7/49. App. 9/8/45. Assign. The Liquidometer Corp.

Liquid Level Measuring Device with Oscillator. A level indicator having a vertical bar pivoted at the bottom of the tank with its upper end supported by a pair of horizontal springs, the system being kept in transverse vibration by a solenoid and feed-back oscillator and the frequency indicated.

216—MAGNETIC COMPASS

U. S. No. 2,466,018. T. M. Ferrill, Jr. Iss. 4/5/49. App. 8/2/46. Assign. The Sperry Corp.

Vibratory Strand Reference Apparatus with Longitudinal Component Drive. A magnetic reference device having an elastic wire in which longitudinal vibrations are produced by magnetostrictive end pieces and through which an a-c is passed so that an ambient field produces transverse vibrations which are detected by condenser plates adjacent to the wire.

U. S. No. 2,466,687. R. V. Craddock and R. S. Curry, Jr. Iss. 4/12/49. App. 8/13/45. Assign. The Sperry Corp.

Integrating and Remote Reading Compass System. A repeating system for a flux-gate compass in which random signal variations are smoothed out by rectifiers in an R-C circuit to prevent jittery indications.

U. S. No. 2,473,516. C. F. Fragola and R. V. Craddock. Iss. 6/21/49. App. 5/29/43. Assign. The Sperry Corp.

Gyro Flux Valve Compass System. A gyro whose orientation is controlled from a polyphase flux-valve compass acting through a grid-controlled oscillator so that full restoring action is brought about by a small orientation error.

220—MAGNETIC LOGGING

U. S. No. 2,470,828. J. W. Millington and W. H. Stewart. Iss. 5/24/49. App. 1/10/46. Assign. Sun Oil Co.

Tube Testing Apparatus. A pipe testing device having a coil on a magnetic core which is run into the pipe, the coil being in one arm of an a-c bridge circuit.

224—MAGNETIC RECORDER

U. S. No. 2,468,198. H. S. Heller. Iss. 4/26/49. App. 8/3/45.

Magazine Type Magnetic Recorder with Multiple Lane Tape and Traversing Transducer. A multi-lane magnetic tape recorder in which the pickup magnets are opened when the magazine is removed and locked on the proper lane when the magazine is replaced.

U. S. No. 2,468,782. D. E. Ross and W. E. Stofer. Iss. 5/3/49. App. 9/11/46. Assign. Herman S. Heller.

Interchangeable Magnetic Transducer and Switching System. A multi-lane magnetic recorder having an erasing magnet preceding the recording magnet and switches arranged to interchange the functions of the magnets when the direction of tape motion is changed.

U. S. No. 2,469,266. H. A. Howell. Iss. 5/3/49. App. 8/14/45. Assign. The Indiana Steel Products Co.

Magnetic Transducer Having an Irregular Nonmagnetic Gap. A magnetic recording head having non-parallel pole faces so as to obtain more uniform frequency response.

U. S. No. 2,469,444. H. E. Roys. Iss. 5/10/49. App. 4/30/45. Assign. Radio Corp. of America.

Magnetic Sound Recording and Reproducing Transducer. A magnetic recording head having a very small magnetic circuit in the form of a loop of thin ribbon with outward-projecting pole pieces.

U. S. No. 2,469,750. D. E. Sunstein. Iss. 5/10/49. App. 7/3/45. Assign. Philco Corp.

Magnetic Transducer Adapted to Compensate for Twisting of Record Wire. A magnetic recorder head having two pickup coils at right angles on a ring gear around the record wire, the auxiliary coil being used to operate an orienting motor which rotates the ring gear into a position of maximum reproduced signal.

U. S. No. 2,471,251. H. E. Tompkins. Iss. 5/24/49. App. 9/6/45. Assign. Philco Corp.

Magnetic Transducer Adapted to Compensate for Twisting of the Record Wire. A wire recorder reproducing system which corrects for twisting of the wire by using two pickup coils placed about the wire at 90° and with their outputs separately fed through phase shifters to produce a 90° phase difference between them and the signals then added.

228—MAGNETIC TESTING

U. S. No. 2,467,562. R. DeO. McDill. Iss. 4/19/49. App. 6/21/43. Assign. Thompson Products, Inc.

Method and Apparatus for Magnetically Testing Valves for Sodium Content. A system for testing hollow poppet valves by segregating the internal material in the head at a known angle and rotating in front of a coil in an impedance bridge circuit.

U. S. No. 2,468,154. J. A. Ashworth and R. A. Chegwidden. Iss. 4/26/49. App. 10/5/43. Assign. Bell Telephone Laboratories, Inc.

Premeability Determination. A system for determining the magnetic permeability of objects in situ by inducing a measured flux in the object and measuring the mmf required to neutralize the field gradient over a selected region.

U. S. No. 2,469,476. J. C. Sellars. Iss. 5/10/49. App. 1/13/48. Assign. East Lancashire Chemical Co. Ltd.

Magnetic Testing Apparatus. A device for testing the thickness of a non-magnetic layer on magnetic material and having a permanent magnet with spherical pole pieces which are placed against the layer and between the pole pieces a pivoted soft iron bar with spring and pointer.

U. S. No. 2,470,828. J. W. Millington and W. H. Stewart. Iss. 5/24/49. App. 1/10/46. Assign. Sun Oil Co.

Tube Testing Apparatus. A pipe testing device having a coil on a magnetic core which is run into the pipe, the coil being in one arm of an a–c bridge circuit.

U. S. No. 2,470,839. T. Zuschlag. Iss. 5/24/49. App. 2/5/46. Assign. Magnetic Analysis Corp.

Magnetic Testing with Artificial Standard. A magnetic testing system in which samples are magnetically compared with a standard sample by observation of the induced wave form when the material is used as the core of an open-core transformer, the standard wave form being recorded on an endless magnetic record and reproduced in synchronism with the tests on the samples.

232—MAGNETOMETER

U. S. No. 2,468,554. A. W. Hull. Iss. 4/26/49. App. 3/19/43. Assign. General Electric Co.

Apparatus for Magnetic Field Investigation. A gyro-stabilized total-field magnetometer having orienting elements whose outputs control precession-inducing pneumatic valves and are also squared and added to the magnetometer output to correct for misorientation.

U. S. No. 2,468,968. E. P. Felch, Jr. and T. Slonczewski. Iss. 5/3/49. App. 4/20/43. Assign. Bell Telephone Laboratories, Inc.

Magnetic Field Strength Indicator. A total-field magnetometer having three mutually perpendicular flux-valves mounted on gimbals with two of the flux-valves controlling the orientation of the system through servomotors and with the outputs of the orienting flux-valves squared and combined with the output of the indicating flux-valve.

U. S. No. 2,474,693. R. G. Rowe. Iss. 6/28/49. App. 1/31/45.

Magnetic Field Responsive Device. A magnetic field sensitive device having a magnetostrictive rod mounted at its nodal point without damping and excited by a constant-frequency voltage source, the rod being mechanically connected to a crystal pickup whose output is amplified and indicated.

236—MASS SPECTROMETRY

U. S. No. 2,470,745. C. H. Schlesman. Iss. 5/17/49. App. 5/15/45. Assign. Socony-Vacuum Oil Co., Inc.

Mass Spectrometer. A mass spectrometer of the scanning type and having an auxiliary target over which the beam sweeps before it is brought onto the main target, the auxiliary current being used to control relays which adjust the recording range for the next mass peak.

U. S. No. 2,471,935. N. D. Coggeshall and M. Muskat. Iss. 5/31/49. App. 3/19/45. Assign. Gulf Research & Development Co.

Method and Apparatus for Separating Charged Particles of Different Masses. A mass spectrometer in which space focusing is obtained by having the ions execute cycloidal orbits in a non-uniform magnetic field.

U. S. No. 2,472,870. H. W. Washburn. Iss. 6/14/49. App. 11/21/44. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A mass spectrometer in which the region between the two ion-collimating slits has electrodes for producing a transverse field which may be adjusted for maximum ion-beam intensity.

288—PRESSURE GAUGE

U. S. No. 2,466,809. W. V. Hobbs. Iss. 4/12/49. App. 5/15/44. Assign. Ranco Inc.

Pressure Measuring Apparatus. A pressure gauge in which the pressure is applied to the inside of a tube of oval cross section which is kept in sustained transverse vibration by a contact and magnet and the frequency indicated.

U. S. No. 2,466,846. J. V. Giesler. Iss. 4/12/49. App. 12/27/45. Assign. Robertshaw-Fulton Controls Co.

Pressure Measuring Device. An electrical pressure gauge having a bellows which actuates a contact arm rocking on a resistor and indicating the voltage tapped off.

U. S. No. 2,467,375. J. A. Folse. Iss. 4/19/49. App. 4/5/45.

Pressure Gauge. A maximum pressure gauge having a piston acting against a spring and with a wedging sphere which prevents its return from maximum displacement.

U. S. No. 2,470,714. S. G. Nevius. Iss. 5/17/49. App. 2/9/45.

Electric Pressure Indicator. A pressure gauge having an annular tube whose interior is subjected to the pressure and having filament-type strain gauges mounted on its exterior concave and convex surfaces connected in a bridge circuit.

U. S. No. 2,472,045. C. H. Gibbons. Iss. 5/31/49. App. 12/12/45. Assign. The Baldwin Locomotive Works.

Fluid Pressure Measuring Device. An engine-cylinder pressure gauge in which a diaphragm imparts stress to a tube which carries a bonded filament-type strain gauge and around which a coolant may be circulated.

U. S. No. 2,472,214. H. Hurvitz. Iss. 6/7/49. App. 10/22/47.

Pressure Responsive Electrical Resistor. A pressure-sensitive resistance cell made of electrically-conducting sponge rubber with an impervious outer membrane and a pair of electrodes which extend into the interior sponge rubber.

U. S. No. 2,474,146. C. M. Hathaway. Iss. 6/21/49. App. 7/31/46.

Electric Pressure Head. A pressure gauge having a cylinder with a hollow portion to which the pressure is applied and having a filament-type strain gauge wound around the hollow portion for pressure indication and a similar wire wound around the solid portion for temperature compensation.

U. S. No. 2,474,280. J. Rothstein. Iss. 6/28/49. App. 4/22/46.

Piezometric Thermionic Tube. A pressure-sensitive vacuum tube having a diaphragm in its envelope and a mechanical connection between the diaphragm and an electrode and also an annular baffle behind the diaphragm to produce a desired pressure-deflection function.

U. S. No. 2,474,662. R. C. Fuller. Iss. 6/28/49. App. 12/19/45 and 6/21/46.

Electric Pressure Indicator. A pressure-operated switch having a diaphragm whose deflection actuates a contact and also has a stop to protect the diaphragm against overload.

304—RADIOACTIVITY LOGGING

U. S. No. 2,469,383. C. J. Gibbs and J. H. Stein. Iss. 5/10/49. App. 3/4/44. Assign. Texaco Development Corp.

Method and Apparatus for Removing Random Fluctuations from Intensity Measurements. An arrangement for smoothing out random fluctuations in a well-logging indicator by an R-C circuit, the resistance being shunted by biased diodes so that when large indications are received the time constant is reduced.

U. S. No. 2,469,460. R. E. Fearon. Iss. 5/10/49. App. 4/12/45. Assign. Stanolind Oil and Gas Co.

Radioactivity Measurement. A system for measuring the spectral distribution of gamma rays by using an ionization chamber filled with an inert gas which produces no negative ions and separately measuring the ionization electrons from each quantum absorbed by means of an arrangement of grids and shields in the chamber.

U. S. No. 2,469,461. W. L. Russell. Iss. 5/10/49. App. 1/4/46. Assign. Stanolind Oil and Gas Co.

Gamma-Ray Logging. A system of well logging for gamma-ray scattering in which the source and detector are closely adjacent and both are held in contact with the formation wall.

U. S. No. 2,469,462. W. L. Russell. Iss. 5/10/49. App. 1/18/46. Assign. Stanolind Oil and Gas Co.

Neutron Well Logging. A neutron well logging system using a source of fast neutrons and two gamma-ray detectors one of which is spaced a distance from the neutron source at which the slow neutron concentration is independent of formation hydrogen and the other located at a distance such that its response is an inverse function of porosity.

U. S. No. 2,469,463. W. L. Russell. Iss. 5/10/49. App. 1/18/46. Assign. Stanolind Oil and Gas Co.

Neutron Logging of Wells. A neutron well logging system using a source of neutrons and two gamma-ray detectors one of which has a boron shield and is spaced from the source so that its indication is independent of formation hydrogen content and the other having a shield with large capture cross section for slow neutrons.

U. S. No. 2,470,224. S. A. Scherbatskoy. Iss. 5/17/49. App. 12/6/44. Assign. Well Surveys, Inc.

Ionization Chamber. An ionization chamber containing gas at high pressure and having a grid located between the outer and inner electrodes, the grid having applied to it a direct and an alternating potential so as to produce a periodically varying ionization current which is easily amplified.

U. S. No. 2,474,581. L. G. Howell. Iss. 6/28/49. App. 4/19/45. Assign. Standard Oil Development Co.

Well Logging. A method of radioactivity logging using two detectors having different degrees of response and separated by a known distance so that spurious effects can be recognized by comparing the two records.

308—RADIOACTIVITY MEASUREMENTS

U. S. No. 2,468,905. J. B. Warren, Jr. Iss. 5/3/49. App. 6/11/43.

Means for Detecting Wear on Bits. A drill bit having a compressed radioactive fluid in a capsule in the bit so that when the bit is worn the contents of the capsule are released into the mud stream and may be detected at the surface.

U. S. No. 2,472,153. R. E. Fearon. Iss. 6/7/49. App. 1/13/45. Assign. Well Surveys, Inc.

Method and Apparatus for Detecting Radiations. A radiation detector having a sealed system in which an ionizable gas is circulated past arrays of electrode plates in the neighborhood of which ionization and deionization of the gas takes place.

U. S. No. 2,472,365. C. J. Borkowski. Iss. 6/7/49. App. 2/21/46. Assign. U. S. A.

Alpha Particle Counting. An ionization chamber having a cylindrical outer wire mesh at ground potential and a smaller concentric tube at high potential and an insulated rod inside the tube connected to the grid of an amplifier.

U. S. No. 2,474,773. W. R. Baker. Iss. 6/28/49. App. 11/6/47. Assign. U. S. A.

Radiation Detector. An ionization chamber having an outer chamber with a covered port for the entrance of radiation and an inner chamber with a grid and plate opposite the port and containing a cathode-follower amplifier circuit.

312—RADIO NAVIGATION

U. S. No. 2,468,090. F. J. Lundburg. Iss. 4/26/49. App. 5/21/45. Assign. Federal Telephone and Radio Corp.

Location Finder. A radio navigation system in which two or more ground stations with rotating directive antennas intercept an identified interrogation signal from the mobile station and return a signal repeating the identification and also signaling the azimuthal angle.

U. S. No. 2,470,787. P. W. Nosker. Iss. 5/24/49. App. 5/4/44.

System for Determining the Position or Path of an Object in Space. A system for locating a mobile station from three ground stations in which each station transmits a modulated carrier and the various phase relations compared.

U. S. No. 2,471,648. W. J. O'Brien. Iss. 5/31/49. App. 3/2/42 and 11/8/43. Assign. The Decca Record Co., Ltd.

Equisignal Radio Beacon System. An "on course" and "off course" radio beacon system in which two antennas radiate the same frequency and the signals are automatically interrupted so that the on period of one signal overlaps the on period of the other and the time both signals are on is different from the length of time in which only one signal is on.

316—RADIO RANGING

U. S. No. 2,466,539. J. Evans. Iss. 4/5/49. App. 2/20/43. Assign. Radio Corp. of America.

Pulse-Echo Distance Indicator. A radio pulse-echo system in which the charging of a condenser is initiated by the transmitted pulse and the condenser discharged through a tube made conducting by the reflected pulse and the charge indicated on a meter.

U. S. No. 2,467,202. P. C. Gardiner. Iss. 4/12/49. App. 2/27/46. Assign. General Electric Co.

Pulse-Echo System. A radio pulse-echo system in which a directive antenna is rotated in synchronism with an arm over a sensitized recording chart, and a series of rings under the chart connected to sections of a transmission line so that a mark is made on the chart at the reflection azimuth and radial distance.

U. S. No. 2,467,208. W. C. Hahn. Iss. 4/12/49. App. 12/30/43. Assign. General Electric Co.

Pulse-Echo System. A radio pulse-echo system in which adjustable pulses subsequent to transmission are applied to two parallel tubes in series with the receiver so that reflections with desired delay times may be segregated.

U. S. No. 2,467,455. C. G. P. Aurell. Iss. 4/19/49. App. 5/17/43 and 5/11/44. Assign. Telefonaktiebolaget L. M. Ericsson.

Radio Speed and Distance Indicator. A frequency-modulated radio ranging system in which the reflected signal is combined with the transmitted signal to produce a beat note and the amplitude of its a-c component and magnitude of its d-c component measured.

U. S. No. 2,467,670. W. D. Hershberger. Iss. 4/19/49. App. 7/28/39. Assign. Radio Corp. of America.

Radio Pulse Echo System Using Doppler Effect. A radio ranging system in which the transmitted pulse is also put on a mismatched sectional transmission line and received reflections compared with the reflections in the transmission line.

U. S. No. 2,468,093. N. Marchand. Iss. 4/26/49. App. 7/3/45. Assign. Federal Telephone and Radio Corp.

Electrical Energy Comparison System and Method. A radio direction finder in which the relative amplitudes of signals from two antennas are compared by shifting the phase of one by 90° and impressing them on opposite corners of a transmission-line bridge, the signals from the other opposite corners of the bridge being compared in phase.

U. S. No. 2,468,751. W. W. Hansen and R. H. Varian. Iss. 5/3/49. App. 1/16/42. Assign. The Sperry Corp.

Object Detecting and Locating System. A radar system in which two nearly equal frequencies are transmitted and the reflecting object's velocity obtained from the beat frequency between the reflected and transmitted signals and its distance determined by the phase shift between the two beats on the two transmitted frequencies.

U. S. No. 2,471,412. T. H. Clark. Iss. 5/31/49. App. 10/10/45. Assign. Federal Telephone and Radio Corp.

Frequency Controlled Direction Finder. A direction-finder whose receiver is automatically tuned to an incoming signal by a servo-motor controlled from a frequency-sensitive control circuit energized from a non-directional antenna.

U. S. No. 2,473,175. L. N. Ridenour. Iss. 6/14/49. App. 12/30/43. Assign. U.S.A.

Radio Direction-Finding System. A radar system in which modulation of the reflected signal from a conically-scanning transmitted signal is used to control servo-motors which point the system toward the reflecting object.

U. S. No. 2,473,491. K. Posthumus. Iss. 6/14/49. App. 2/26/44 and 2/8/47. Assign. Hartford National Bank and Trust Co.

Direction Finding Device. A radio direction finder in which two receivers are periodically and alternately connected each to a loop and both to the same loop and the ratio of phase displacements and amplification of the receivers indicated along with the direction bearing.

324—RECORDER

U. S. No. 2,466,186. L. Thompson. Iss. 4/5/49. App. 3/13/43. Assign. The Brush Development Co.

Reverse Re-Recording System. A phonograph recording system in which the original record is re-recorded in the reverse direction on a reversed record and reproduced from the second record in the original direction.

U. S. No. 2,466,691. H. L. Daniels. Iss. 4/12/49. App. 4/9/45.

Electromagnetic Oscillograph. An electromagnetic direct-recording pen-type oscillograph in which the pen is driven by the armature of a variable air-gap reluctance-type transducer.

356—SEISMOGRAPH MIXING

U. S. No. 2,473,469. C. G. Dahm. Iss. 6/14/49. App. 4/10/48. Assign. Socony-Vacuum Oil Co., Inc.

Method and Apparatus for Minimizing the Horizontally-Traveling Components of Seismic Waves. A system of seismograph mixing in which pairs of detectors are spaced various distances apart, their respective signals filtered to pass frequencies whose half wave length corresponds to the separation of the respective pairs, the signals of each pair added so as to cancel horizontally-arriving waves and the outputs of the pairs added.

364—SEISMOGRAPH RECORDER

U. S. No. 2,468,210. B. Kreuzer. Iss. 4/26/49. App. 2/8/45. Assign. Radio Corp. of America.

Noise Reduction Sound System and Method. A system for reducing noise in rerecording by impressing part of the reproduced signal on a reverberation chamber from which it is picked up and recombined with the signal being recorded.

U. S. No. 2,474,303. R. M. Davis. Iss. 6/28/49. App. 3/13/47. Assign. Standard Oil Development Co.

Oscillographic Recording Apparatus. A system for simultaneously making duplicate seismograph records by splitting the light beam with a triangular prismatic mirror so that half the light falls on one tape and the other half on a second tape.

368—SEISMOGRAPH TIMING

U. S. No. 2,469,951. A. G. Cooley. Iss. 5/10/49. App. 10/10/45. Assign. Times Facsimile Corp.

Tuning Fork and Control System. A tuning fork whose tines are enclosed in an evacuated chamber with the base of the fork accessible, the tines being hollow and carrying adjustable internal weights or springs.

372—SEISMOGRAPH VOLUME CONTROL

U. S. No. 2,466,216. A. E. Ekstrand. Iss. 4/5/49. App. 6/13/47. Assign. Stromberg-Carlson Co.

Sound Control System. A system for controlling the amplification level of a public-address system from a microphone which picks up the background noise and actuates a series of relays which short circuit attenuating resistors in the loud-speaker circuit.

U. S. No. 2,467,624. G. B. Loper. Iss. 4/19/49. App. 3/20/46. Assign. Socony-Vacuum Oil Co., Inc.

Signal Transmission Circuit for Seismographs. A volume control circuit for a seismograph amplifier in which the center-tapped secondary of a transformer forms two arms of a bridge with resistors in the other arms, one of them being shunted by a pair of opposed triodes whose grid bias controls the signal level.

U. S. No. 2,468,139. L. N. Theroux. Iss. 4/26/49. App. 3/6/45.

Automatic Volume Control Preamplifier. An avc system in which output from the first stage is rectified, filtered and used to control a tube which loads a tertiary winding on the input transformer.

388—SHOT MOMENT RECORDING

U. S. No. 2,470,846. D. R. De Boisblanc and J. E. Bondurant. Iss. 5/24/49. App. 11/13/45. Assign. Phillips Petroleum Co.

Seismograph Blaster Time Breaker Circuit. A shot moment recording circuit in which the cap is part of one arm of a balanced Wheatstone bridge circuit to which the firing current is applied and unbalance of the bridge upon firing is recorded.

420—SPECTROPHOTOMETER

U. S. No. 2,468,638. E. J. Rosenbaum. Iss. 4/26/49. App. 1/17/45. Assign. Sun Oil Co.

Apparatus for Continuous Analysis of Fluid Mixtures. An apparatus for determining the conjugated diolefin content of a gas stream by measuring its absorption of ultra-violet light from a hydrogen arc which is stabilized by a constant voltage transformer and series resistor.

U. S. No. 2,469,129. G. B. Reimann. Iss. 5/3/49. App. 11/5/45.

Spectrophotometric Curve Reading Apparatus. A device for reading a spectrophotometer curve for determining color having a carriage which moves the graph vertically along a scale and a transparent index which may be moved horizontally along a corrected wave-length scale.

U. S. No. 2,471,248 & 9. E. I. Stearns, Jr. and G. L. Buc. Iss. 5/24/49. App. 10/20/44, 12/27/44 and 3/17/48./Assign. American Cyanamid Co.

Photometric Apparatus and Spectrophotometers Using Polarized Light etc. Apparatus for measuring reflectance of a sample and in which either a plate of optically-active material or a multiple-retardation plate is placed between the sample and the polarizing element so as to make the response from polarizing samples substantially independent of azimuth.

428—STRAIN GAUGE

U. S. No. 2,466,034. H. A. Mathews. Iss. 4/5/49. App. 10/1/46. Assign. Byron Jackson Co.

Tension Measuring Device. A device for measuring tension in drill pipe with internal pressure and having two filament-type strain gauges on a nipple to detect longitudinal strain and circumferential strain, and two compensating gauges mounted on a radially extending shoulder on the nipple.

U. S. No. 2,466,337. A. L. Thurston and J. O. Irwin. Iss. 4/5/49. App. 1/20/45. Assign. Cox & Stevens Aircraft Corp.

Electric Strain Gauge. A filament-type strain gauge in which the filament wire is attached to the terminal wire at an angle of between 56 to 63 degrees so as to avoid end strain effects.

U. S. No. 2,467,738. F. W. Godsey, Jr. Iss. 4/19/49. App. 8/30/46. Assign. Westinghouse Electric Corp.

Strain Responsive Device. A variable air-gap impedance-type strain gauge using a stationary exciting coil and a rotor on a shaft whose torque is measured.

U. S. No. 2,467,752. W. H. Howe. Iss. 4/19/49. App. 8/15/44. Assign. The Foxboro Co.

Wrapped Wire Strain Gauge. A filament-type strain gauge in which the filament is spirally wrapped around a cylindrical core so that tension in the core causes shortening of the wire.

U. S. No. 2,470,051. A. C. Ruge. Iss. 5/10/49. App. 6/14/47. Assign. The Baldwin Locomotive Works.

Electrical Impedance Filament and the Method of Making Same. A wire filament in which zero temperature coefficient of resistance is obtained by having a central core of one material with an outer coating of proper thickness and of another material whose temperature coefficient is opposite to that of the core.

U. S. No. 2,470,626. B. F. Langer and K. L. Wommack. Iss. 5/17/49. App. 8/30/46. Assign. Westinghouse Electric Corp.

Electromagnetic Torque Responsive Device. A torque strain gauge for a rotating shaft and having a stationary coil surrounding the shaft with a series of saw tooth variable air gaps on an armature on the shaft.

436—SUBMARINE SIGNALING

U. S. No. 2,466,112. A. C. Keller. Iss. 4/5/49. App. 12/31/42. Assign. Bell Telephone Laboratories, Inc.

Compressional Wave Translating Device. A piezoelectric hydrophone having a stack of longitudinally-active crystals mounted so that alternate crystals have their longitudinal axes at right angles in order to attain a circular propagation and reception pattern.

U. S. No. 2,467,368. L. Batchelder. Iss. 4/19/49. App. 9/23/43. Assign. Submarine Signal Co.

Submarine Sound Direction Determining System. A method of echo ranging in which two slightly divergent beams are directed at the target and the direction of the target determined by balancing the intensity of the reflections from the two beams.

U. S. No. 2,468,837. R. L. Peek, Jr. Iss. 5/3/49. App. 8/2/45. Assign. Bell Telephone Laboratories, Inc.

Magnetostrictive Transducer. A supersonic hydrophone having an annular magnetostrictive core with radial polarizing magnets and the core excited to produce out-of-phase vibration of arcuate sections at a harmonic above the fundamental frequency.

U. S. No. 2,472,107. H. C. Hayes and E. Klein. Iss. 6/7/49. App. 5/6/36.

Acoustical Apparatus. A transducer mounting for the hull of a ship with the opening in the hull covered on the outside by a sound-transparent material and the transducing unit mounted from the inside so it may be removed for inspection.

U. S. No. 2,473,354. H. Benioff. Iss. 6/14/49. App. 11/20/42 and 1/10/48. Assign. Submarine Signal Co.

Device for Transmitting and Receiving Compressional Waves. A magnetostriction hydrophone having a number of resonators mounted at their nodal points on the front plate and with driving units at their inner ends.

U. S. No. 2,473,846. L. E. Barton. Iss. 6/21/49. App. 11/30/42 and 6/2/47. Assign. Radio Corp. of America.

Electroacoustic Transducer. A directional hydrophone having a number of magnetostrictive tubes fastened to the back of the diaphragm and distributed so that the associated diaphragm mass is from four to seven times the mass of its driving unit.

U. S. No. 2,473,971. D. E. Ross. Iss. 6/21/49. App. 2/25/44. Assign. U.S.A.

Underwater Transducer. A submarine-signaling transducer whose case has a sound-transparent window and whose motor unit is suspended in the case by layers of a cork and rubber mixture having low acoustic impedance.

440—SURFACE TESTING

U. S. No. 2,471,009. R. E. Reason. Iss. 5/24/49. App. 5/13/43 and 8/15/44. Assign. Taylor, Taylor & Hobson Ltd.

Apparatus for Measuring or Indicating the Roughness or Undulations of Surfaces. A surface testing device having a blunt stylus and a sharp stylus and their relative motion indicated by an electric pickup.

U. S. No. 2,474,015. H. Shaw. Iss. 6/21/49. App. 1/22/45 and 2/14/45.

Instrument for the Measurement of Surface Finishes. A device for measuring the length or area of contact of a surface by moving across it a reference surface with a stylus whose vertical displacements control an integrator.

448—TENSION INDICATOR

U. S. No. 2,466,034. H. A. Mathews. Iss. 4/5/49. App. 10/1/46. Assign. Byron Jackson Co.

Tension Measuring Device. A device for measuring tension in drill pipe with internal pressure and having two filament-type strain guages on a nipple to detect longitudinal strain and circumferential strain, and two compensating gauges mounted on a radially extending shoulder on the nipple.

U. S. No. 2,471,999. A. Boos. Iss. 5/31/49. App. 10/30/45. Assign. John Chatillon & Sons.

Cable Tensiometer. A cable tensiometer having a member which contacts one side of the cable and two pressure elements which contact the other side of the cable and tend to bend it around the first member with the deflection produced by a spring being indicated.

U. S. No. 2,472,142. J. J. Boulin. Iss. 6/7/49. App. 11/8/46. Assign. Boulin Instrument Corp.

Tensiometer. A device for indicating tension in a running line and having three pulleys two of which bear on one side of the line and the center one on the other side and its deflection indicated.

U. S. No. 2,472,845. R. S. Neiswander. Iss. 6/14/49. App. 8/31/44.

Tensiometer. A cable tensiometer having two grips which clamp two points of the cable and pull them together enough to cause a slight slack and measures the tension by the deflection of a spring in the support of one of the grips.

460—THERMOMETER

U. S. No. 2,470,653. E. L. Schulman and A. C. Beiler. Iss. 5/17/49. App. 1/10/48. Assign. Westinghouse Electric Corp.

Resistance Thermometer. An electrical resistance thermometer having an element of an alloy whose specific resistance is twenty five times greater than that of copper and whose temperature coefficient of resistance is equal to that of copper.

U. S. No. 2,472,759. A. Raspet. Iss. 6/7/49. App. 5/3/45.

Thermopile for Measuring Air Temperatures. A thermopile having a cylindrical metal container for cold-junction refrigerant surrounded by a metal jacket in which the cold-junctions are embedded and with an outer jacket of insulating material through which the hot junctions protrude.

U. S. No. 2,474,192. C. H. Schlesman. Iss. 6/21/49. App. 4/25/44. Assign. Socony-Vacuum Oil Co., Inc.

Electronic Curve Plotting Device. A system for indicating a series of temperatures or other parameters on a c-r tube screen by means of a succession of vertically-displaced sweeps during each of which the tube is connected to an emf corresponding to a different one of the parameters by a synchronous commutator.

484—TRANSDUCER

U. S. No. Re. 23,125. (*Orig. No. 2,405,433.*). H. Koch. Iss. 6/21/49. App. 12/31/41, 8/6/46 and 6/28/47. Assign. Dictograph Products Co., Inc.

Bone Conduction Hearing Aid. A hearing aid in which the transducing element is mounted on the bone-engaging contactor and the entire system resiliently suspended from the case.

U. S. No. 2,466,591. H. L. Daniels. Iss. 4/12/49. App. 4/9/45.

Electromagnetic Oscillograph. An electromagnetic direct-recording pen-type oscillograph in which the pen is driven by the armature of a variable air-gap reluctance-type transducer.

U. S. No. 2,467,127. H. N. Hall and J. G. Woodward. Iss. 4/12/49. App. 3/14/46. Assign. Radio Corp. of America.

Mounting for Magnetostrictive Driving Units. A magnetostrictive transducer in which the magnetostrictive rods are held by washers bonded to the diaphragm and the coil forms are also fastened to the washers.

U. S. No. 2,468,270. H. F. Olson and J. Preston. Iss. 4/26/49. App. 12/30/44. Assign. Radio Corp. of America.

Magnetostrictive Transducer. A magnetostrictive transducer having integral driving units which may be independently tuned and subsequently screwed to a thin diaphragm to drive it in unison.

U. S. No. 2,468,537 & 8. H. Benioff. Iss. 4/26/49. App. 7/23/45 and 1/10/46. Assign. Submarine Signal Co.

Ultra High Frequency Vibrator. A piezoelectric ultrasonic vibrator whose crystal has one side free and the other side in contact with a liquid into which may be immersed another container with a thin diaphragm and containing material to be vibrated.

U. S. No. 2,468,837. R. L. Peek, Jr. Iss. 5/3/49. App. 8/2/45. Assign. Bell Telephone Laboratories, Inc.

Magnetostrictive Transducer. A supersonic hydrophone having an annular magnetostrictive core with radial polarizing magnets and the core excited to produce out-of-phase vibration of arcuate sections at a harmonic above the fundamental frequency.

U. S. No. 2,469,005. J. L. Russell. Iss. 5/3/49. App. 2/8/47. Assign. The Bristol Co.

Magnetostrictive Condition-Responsive Apparatus. A device for converting a small d-c to a-c by applying the d-c to a core of magnetostrictive material which is periodically stressed by an electromechanical vibrator and the resulting a-c taken from secondary coils on the core.

U. S. No. 2,469,417. S. Stein. Iss. 5/10/49. App. 6/13/45.

Torsional Vibration Pickup. A torsional vibration pickup having an inertia mass mounted on ball bearings and carrying permanent magnets and an armature and coil rigidly connected to the shaft with connections brought out through slip rings.

U. S. No. 2,469,785. F. Rieber. Iss. 5/10/49. App. 1/29/44. Assign. Interval Instruments, Inc.

Frequency Controlled Transducer. An electrical transducer or filter in which the input current is passed through an adjustably tensioned wire in a magnetic field and its vibrations picked up electrostatically by an adjacent electrode.

U. S. No. 2,469,933. H. F. Schwarz. Iss. 5/10/49. App. 6/18/45 and 10/10/45.

Electromagnetic Pickup. A phonograph pickup for lateral-cut records having an armature extending through a coil and vibrated between the poles of two permanent magnets on the under side of the housing.

U. S. No. 2,471,542. S. R. Rich. Iss. 5/31/49. App. 10/25/45.

Phonograph Pickup Unit Using Magnetostrictive Wire. A phonograph pickup having a stylus extending from the midpoint of a magnetostrictive wire which is mounted in torsion between the poles of a permanent magnet with pickup coils around the two ends of the wire.

U. S. No. 2,471,601. R. B. Albright. Iss. 5/31/49. App. 4/28/44. Assign. Philco Corp.

Variable Resistance Phonograph Pickup. A phonograph pickup in which motion of the stylus produces deformations and resistance changes in a conducting composition of rubber and graphite which is connected in circuit with a battery and transformer.

U. S. No. 2,472,388. A. L. Thuras. Iss. 6/7/49. App. 1/15/44. Assign. U.S.A.

Magnetostrictive Oscillator. A magnetostrictive oscillator having a toroidal nickel tube with a circular coil inside the tube.

U. S. No. 2,472,637. C. S. Weyandt. Iss. 6/7/49. App. 12/14/46.

Vibratory Motor. A variable air-gap type electro-mechanical vibrator having rubber bumpers which strike stop-screws to impart vibration to the base.

U. S. No. 2,472,714. F. Massa. Iss. 6/7/49. App. 4/16/45.

Piezoelectric Sound Pressure Microphone. A sound-pressure cell made of a cylindrical housing with a thin diaphragm over one end and an even number of expander-type crystals between the diaphragm and the base of the housing.

U. S. No. 2,472,770. L. L. Helterline, Jr. Iss. 6/7/49. App. 11/20/45. Assign. Sylvania Electric Products, Inc.

Resistance Apparatus for Converting Mechanical Movement into Electrical Pulses. A phonograph pickup in which lateral vibrations of the stylus are mechanically converted into pressure variations of a cat whisker on a semiconducting crystal in the input circuit of an implifier.

U. S. No. 2,473,354. H. Benioff. Iss. 6/14/49. App. 11/20/42 and 1/10/48. Assign. Submarine Signal Co.

Device for Transmitting and Receiving Compressional Waves. A magnetostriction hydrophone having a number of resonators mounted at their nodal points on the front plate and with driving units at their inner ends.

U. S. No. 2,473,650. H. P. Kalmus. Iss. 6/21/49. App. 6/10/43. Assign. Zenith Radio Corp.

Phonograph Pickup with Mechanical Filter. A phonograph pickup in which the stylus moves a coil so as to change its inductance for f-m reproduction, the coil and stylus being mounted on a double elastic system to provide a mechanical filter.

U. S. No. 2,473,820. H. K. Richards. Iss. 6/21/49. App. 2/20/47. Assign. Raytheon Manufacturing Co.

Magnetron-Type Phonograph Pickup. A phonograph pickup in which the stylus vibrates pole pieces of a permanent magnet so as to change the radial electron current in a cylindrical diode.

U. S. No. 2,473,835. E. E. Turner, Jr. Iss. 6/21/49. App. 8/6/42 and 3/17/48. Assign. Submarine Signal Co.

Means for the Interchange of Electrical and Acoustical Energy. A piezoelectric transducer having a series of crystals stacked crosswise 90° to each other with the ends of the crosses in contact with the inner surface of a cylindrical sound radiator.

U. S. No. 2,473,846. L. E. Barton. Iss. 6/21/49. App. 11/30/42 and 6/2/47. Assign. Radio Corp. of America.

Electroacoustic Transducer. A directional hydrophone having a number of magnetostrictive tubes fastened to the back of the diaphragm and distributed so that the associated diaphragm mass is from four to seven times the mass of its driving unit.

U. S. No. 2,474,197. G. L. Dimmick. Iss. 6/21/49. App. 5/31/40. Assign. Radio Corp. of America.

Electromagnetic Sound Powered Telephone. A telephone transducer having a diaphragm connected to the armature of a magnetic bridge transducing element through a rod which has a symmetrical accordion-like flexible link.

492—VIBROMETER

U. S. No. 2,469,137. E. C. Strong. Iss. 5/3/49. App. 10/20/45. Assign. Waugh Equipment Co.

Vibration Indicator. A magnetic vibration pickup having a spring-suspended armature which may vibrate longitudinally along the axis of a pair of coils one of which is excited by a-c and the other connected to an indicator.

U. S. No. 2,472,127. F. K. Slason. Iss. 6/7/49. App. 2/15/46.

Temperature Compensated Vibration Pickup. An electromagnetic vibrometer having an annular permanent magnet suspended on springs, the magnet carrying between its pole pieces a magnetic shunt of a material having a negative temperature coefficient of permeability.

U. S. No. 2,474,408. T. C. Van Degrift. Iss. 6/28/49. App. 3/19/45. Assign. General Motors Corp.

Torsional Vibration Exhibiting Means. A mechanically recording device for making a record of the torsional vibration of a crankshaft and having an inertia mass connected to the shaft through a spiral spring and with a stylus connected by levers to the mass and to a radius arm from the shaft.

496—VISCOSIMETER

U. S. No. 2,468,370. K. T. Källe. Iss. 4/26/49. App. 11/30/45 and 11/29/46.

Apparatus for the Automatic Indication of the Viscosity or Concentration in Liquids. A rotating cylinder viscosimeter which is driven by a constant-pressure variable-speed turbine and carries on its shaft a cylindrical container with liquid forming a parabolic surface of rotation in which the depth of the liquid is determined by measuring the air-bubble pressure.

520—WELL SURVEYING

U. S. No. 2,466,251. P. W. Martin. Iss. 4/5/49. App. 2/28/44.

Method of and Apparatus for Measuring the Length of Magnetic Material. A system for measuring off lengths of steel cable or pipe as it is lowered into a well by making a magnetic mark on the cable, the marking device and pick-up being a known distance apart and with the pick-up automatically actuating the marking device and also a counter.

U. S. No. 2,471,644. J. F. Moore, Jr. Iss. 5/31/49. App. 6/4/48.

Length Metering Apparatus for Drill Pipe and the Like. A system for measuring the length of drill pipe going in or out of a well and having a weight-operated electric switch below the hook with an electric cable from the hook to a measuring wheel and counter, the counter operating only when weight on the hook closes the switch.

REVIEWS

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L'analyse des Seismogrammes (*The Analysis of Seismograms*), by Henri Labrouste. Mémoriales des Sci. Phys.; Acad. des Sci. de Paris, Fasc. XXVI. Published by Gauthier-Villars, Paris, 1934.

This little book by the late Doctor Labrouste, Professor on the Faculty of Science of Paris, deserves to be better known by geophysicists than it seems to be. It is really an excellent critical summary of methods that had been used up to the time of its publication for the recognition and analysis of the successive events recorded by a modern seismograph. For this purpose it retains its full validity today. The last and by far the longest chapter is devoted to a discussion of various methods of harmonic analysis, including an important one by the author himself, which have wide applications in other fields of geophysics.

In the first chapter the author presents the problem of deciphering the seismographic record of an earthquake and proceeds step by step and hand in hand with theory to show how far the appearance of the records of earthquakes at various distances has led historically to a knowledge of the nature and the paths of the propagation of the successive wave trains that leave their traces on a typical seismogram. These, in the literature of seismology, are called successive "phases" of the record.

In the second chapter the author brings out in clear relief the essential part that has been played in this interpretation by the world wide network of seismographic stations. By noting the times of first arrival at a large number of stations of the waves from an earthquake whose location is known and by plotting these times as ordinates against the arcual distances from the origin of the earthquake to the respective stations as abscissae, it was found that, within certain ranges of distance, the plotted points lay along a continuous curve, but that there were several such segments with discontinuities between them and that these segments were each concave to the axis of abscissae. With a knowledge of the time of occurrence of the earthquake, these segments of the arrival time curve became corresponding segments of a travel time curve for first arrivals. A similar procedure was followed for succeeding onsets. These travel time curves automatically fell into two classes, those which were concave to the distance axis and those which were straight lines, those of the first type corresponding to body waves and those of the second type to surface waves. A further analysis of these curves led to a knowledge of earth structure. The author, however, goes a step farther and stresses the advantages to be derived from a network with very short distances between stations.

In the third chapter Doctor Labrouste describes the use at a single station of three perpendicular components to study the successive orientations of the displacement vectors and their projection on the plane of propagation and its normal. In the fourth chapter he describes the use, in each of the three components, of several seismographs of quite different natural periods and other dynamic characteristics in order to segregate and emphasize for study individual types of vibration that are arriving simultaneously at the station by the same or entirely different paths. Every pendulum is a dynamic filter with reference to impressed wave trains; and if the relative motion between the pendulum and the ground is recorded electromagnetically through a galvanometer, a double filtering effect occurs. In any case, the calculation of the true ground motion from the ordinates which are read from a seismogram is a very difficult problem except in the case of a few special types, such as undamped sinusoidal waves, which are very rare in nature. On the other hand, the use of seismographs

of short, medium and long period in each of three perpendicular directions greatly facilitates the separation of the "phases" on the seismograms and provides a more complete record of the ground movement. The author's thorough physical and mathematical training and his years of intimate contact with these problems while on the staff of the Geophysical Institute at the University of Strasbourg impart to his discussions and critiques a sense of balance and of perspective that is refreshing and reassuring.

Coming now to Chapter V, one finds a mine of useful information concerning methods that have been applied to analyze seismograms into elementary components. The author divides these methods into three classes: application of Fourier analysis; decomposition into any kind of simple undamped harmonic vibrations either by experiment or by calculation; and, thirdly, graphical analysis by linear combinations, which, within certain limits, can be applied even to damped oscillations. Fourier analysis is not satisfactory because it assumes that the elementary components of a seismogram are undamped and strictly periodic with periods that are submultiples of some fundamental period. It is not at all evident in any particular case that this assumption is justified and even the choice of the fundamental will be entirely arbitrary. In the second class of methods, undamped periodicity is presumed in all the components, but no assumption is made as to interdependence or interrelation of periods. In the third class the author describes very briefly his own method of graphic analysis by linear combinations. He supposes an enlargement of that portion of the seismogram which is to be studied to be plotted on a rectangular coordinate paper. The time axis of the curve is taken as axis of abscissae so that displacements of the curve from the zero or equilibrium position will be read as ordinates. The author first considers a curve made up of similar components of constant amplitude. Taking the distance between two adjacent rulings on the coordinate paper as unity, a point x_0 is chosen on the axis of abscissae. The corresponding ordinate will be y_0. Reading the ordinate at the distance m to right of y_0 as y_m and the one at the distance $-m$, toward the left of y_0, as y_m^1, he replaces y_0 by the sum $Y_m = y_m + y_m^1$. Repeating this process for all the points on the graph, a new curve is obtained which has these properties: each of the unknown elementary components has been replaced by a new sinusoid similar to it, that is having the same period and the same phase but of modified amplitude in general. The corresponding ordinate of each of the component sinusoids will be multiplied by an amplitude factor a which is a function of the distance m and of its period n. It can be shown that

$$a = 2 \cos \frac{2\Pi m}{n} \cdot$$

Obviously an analogous result would seem to be obtained by substituting for y_0 the difference, $Z_m = \pm (y_m - y_m^1)$. But this transforms each initial component into a new sinusoid which is in quadrature with the first. In order to reestablish the phase it is necessary to use two successive combinations of the Z type for each combination Y. The amplitude factor for the Z combination will be

$$b = 2 \sin \frac{2\Pi m}{n} \cdot$$

However, to isolate all the components it is usually necessary to supply more complex combinations, $\sum_0^m Y$ and $\sum_0^m Z^2$ and further combinations of each of these.

This method of analysis may be applied to damped oscillation provided that in the given interval the change in amplitude is not too great. Suppose, for example, that in the oscillation

$$y = f(x) \sin (px + k)$$

the function of x can be developed by Taylor's series and only the first two terms need be considered. Then by proper choice of interval the derivative term in the linear combination can be made to vanish, thus reducing the case to that of constant amplitudes. In general the results for damped oscillations are approximate; but in two cases, linear decrease and exponential decrease of amplitude, they are theoretically rigorous. The method is applicable to a wide range of geophysical phenomena and its use is greatly facilitated by a volume of tables prepared jointly with Madame Y. Dammann Labrouste.

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JAMES B. MACELWANE, S. J.

Railway Traffic and Roadbed Seismicity: An Experimental Study. By D. D. Barkan. *Inzhenernii Sbornik* (*Engineering Review*). Published by the Mechanics Institute of the Academy of Science of the USSR. Vol. III, No. 1. Moscow, 1946.

Although the author does not state the purpose of his studies, it appears that he was concerned with the strength and stability of a railway roadbed and that he has approached this problem by studying the vibrations of the roadbed during passage of a train. The instrument used in his field studies was a Geiger Vibrometer, a modification of the pallograph, with a magnification factor of 10. His data were treated statistically.

The section of track used for the experiments was laid on a roadbed of sand, gravel, and shingle. The speeds at which the trains moved were extremely low when compared with usual speeds of rail traffic in this country. They ranged from ten to seventy-five kilometers per hour, i.e., from 6 to 45 mph., with most of the runs occurring at from 40 to 45 kilometers per hour. The water table was at a depth of 2½ meters. The study, incidentally, was concerned only with the vibrations set up by the passage of the locomotive; the effects of the cars it pulled did not concern the investigator.

The amplitude of the vibrations depends upon the speed of the locomotive. The relationship is strictly linear—i.e., the slope does not change from one speed range to another. It should be noted that Barkan was measuring Rayleigh waves, inasmuch as his instrument was of a vertical type. The scatter of observed amplitudes, however, does decrease markedly as speed increases.

The empirical equation which Barkan derived for amplitude, however, is somewhat more complicated. The trace amplitude at any given point within the instrument's range is given by the relationship

$$A = \eta A_0 v (r/r_0)^{i/2} \exp\,(-a(r-r_0)-\xi h)$$

where r and r_0 are distances from the center line of a rail, in centimeters, for which distances the trace amplitudes are A and A_0, respectively, h is the depth of flexure of the rail, ξ is a factor governing amplitude at depth, and η is a proportionality factor.

Barkan calls attention to the fact that the trace is broken when the forward truck of the locomotive crosses a rail joint; the following locomotive wheels that cross the joint do not appear on the record at all. This is ascribed to the fact that the impact of the front wheels upon a rail end is extremely strong—so strong that the rail does not recover by the time the other wheels roll onto it. While the amplitude depends upon the locomotive speed, the period is the same as the vibratory period of the locomotive.

Barkan's theoretical point of departure, incidentally, is classical rail flexure theory, One should like to see the same problem approached from the standpoint of Rayleigh wave theory.

MARK E. BURGUNKER

"Highlights on 1948 Developments in Foreign Petroleum Fields" by L. G. Weeks, *Bull. Amer. Assoc. Petroleum Geologists*, v. 33 (1949) Pp. 1029–1124.

This is the third successive year that Mr. Weeks has prepared his annual review of foreign petroleum activity for the A. A. P. G. Bulletin's "Review of Exploration and Developments" issue. Almost 100 pages in length, the paper is detailed and comprehensive and it is evident that the author has gone to an enormous amount of effort in compiling and presenting his data. Most of the informa-

WORLD-WIDE GEOPHYSICAL ACTIVITY IN 1948 IN PARTY OR CREW MONTHS*

Country	Seismic	Gravity	Magnetic	Electrical
Alaska	21	—	—	—
Canada	381	109	8	—
United States	5,520	1,320	200	?
Mexico	160	47	—	12
Guatemala	—	13	—	—
Nicaragua	4	—	—	—
Bahamas	7	5	—	—
Cuba	6.5	8	1	—
Trinidad	?	24	—	—
Venezuela	285	102	1	—
Colombia	100	56	37 (a)	—
Peru	12	12	—	—
Chile	14	12	—	—
Argentina	?	?		
Paraguay	34	—	—	—
Brazil	24	15	—	—
Great Britain	12	12	12	—
Netherlands	31	12		
France	18	16	—	10 (b)
Denmark	12	6	—	—
Germany	157 (c)	26 (d)	—	—
Hungary	?	35?		?
Russia	?	?	?	?
Italy	30	8	—	6 (b)
French Morocco	12	12	12	19 (e)
Algeria	—	1	—	—
Tunisia	—	11	—	2 (b)
Nigeria	8	8	—	—
French Equat. Africa	—	8	8	—
Mozambique	—	—	3 (f)	—
Madagascar	—	16	8	—
Egypt	24	17	11	—
Turkey	18	9	—	—
Cyprus	4	—	—	—
Transjordan	—	4	4	—
Syria	3	12	8	—
Iraq	14	12	8	—
Qatar	3	—	—	—
Trucial Coast	2	6	3	—
Arabia	12	27	—	—
Bahrein	2	—	—	—
Kuwait	1	—	—	—
Iran	34 (g)	—	—	—
Pakistan	18	4	—	—
Philippines	—	?	—	—
Netherlands East Indies	25	42	—	—
British Borneo	8	—	—	—
Papua & E. New Guinea	2	12	8	—
Portuguese Timor	—	4	—	—
Australia	—	8	8	—

* A dash (—) indicates no activity while a question mark indicates activity, or probable activity, but of unknown amount.

Meaning of other symbols:

(a) Does not include aerial magnetic survey by Gulf in Llanos basin east of Andes.
(b) Telluric current method.
(c) Comprising 146 reflection and 11 refraction crew-months.
(d) Includes 5 torsion-balance crew months.
(e) Includes 12 crew months by telluric current method.
(f) Aerial magnetometer.
(g) Divided between 24 refraction and 10 reflection crew-months.

tion, as might well be expected, is on production statistics and reserves, but interspersed throughout are facts and figures on geophysical activity in all parts of the world. Fortunately, the statistical information on foreign geophysical work is summarized in a single table (p. 1123), portions of which are reproduced on page 585.

Very striking is the wide distribution of geophysical activity in virtually all parts of the world. Seismic work is, as would be expected, in the forefront almost everywhere although gravity surveys are well ahead in the East Indies. The virtual domination of electrical prospecting activity, at least in the search for petroleum, by telluric current methods is a new development of interest. The consistency of the question marks opposite Russia should surprise no one.

MILTON B. DOBRIN

"Gravity Data Obtained in Great Britain by the Anglo-American Oil Company, Limited" by Peter H. N. White, *Quarterly Jl. of the Geol. Soc. London*, vol. CIV, pt. 3, (1949) Pp. 339–364.

This is one of the most comprehensive reports on the results of a commercial gravity survey ever published in a scientific journal. The work covered more than 20,000 square miles. About three quarters of this area was in northern England and adjoining portions of Scotland and Wales. The remainder was along the Channel coast adjacent to the Isle of Wight. About half of each zone lies over structural basins where prospects for petroleum were considered favorable. Surveys in the basins were consequently much more detailed, with much denser station spacing than in the remaining areas, where only regional data were secured.

The survey gave valuable information on regional gravity in Great Britain and in addition revealed some structural features which led to more detailed investigations by seismic methods and subsequently to drilling. No oil was discovered, a fact attributed to the "improbability, geologically, of finding oil on a large scale in the United Kingdom." The area being of no further commercial interest, the gravity results have been turned over to the British government's Ordnance Survey, which can put them to use in its geodetic work. The gravity data also give considerable information on the subsurface geology in the areas covered. Appearing as it does in a geological publication, this paper emphasizes the correlation of the gravity results with the known geology in the respective regions. It also points out the new geologic inferences that might be drawn from the gravity maps.

The author goes into much more than the usual detail when he describes the instrumental procedure, operating methods, reductions, corrections, and accuracy of the results. In a way it is regrettable that authors of most papers reporting geophysical surveys expect their readers to take such things for granted and accept all final results at their face value. Perhaps the high cost of publication makes such omissions necessary, but in a field such as geophysics, where the final results depend so critically on refinements of operating, reducing, and interpretative procedure, it should be an indispensable requirement that the reader have enough information to be able to assess the validity of the conclusions himself.

The gravimeter survey was tied to previously occupied pendulum stations so that absolute gravity values could be established at all gravimeter stations. Bouguer anomalies were computed with more than usual attention to variations in the density of the subsurface rocks. Four different densities were used for one area in conformity with changes of lithology observed in the surface rocks. This may have been a case of overcorrecting, since it is not usually possible to extrapolate such changes reliably in the downward direction.

In discussing instrumental adjustments the author remarks that the gravimeter (a Carter type C) would become highly unstable for several days following periods of bad weather and high winds. Although he attributes this to "some sort of ground motion" he does not appear to be familiar with the considerable body of recent research relating storms at sea with microseisms.

The results are presented both in contour maps of Bouguer anomalies and also in residual maps with regional gravity effects removed. None of the contour maps shows actual station locations and it is difficult to evaluate their accuracy. A number of profiles taken from the Bouguer anomaly maps

show comparisons of gravity with known geology. Some geological features are reflected quite distinctly in the gravity profiles while others appear to have no effect at all. In general the gravity data provide the order of magnitude of the depth to density discontinuities associated with lithologic and stratigraphic contacts. The Cheshire Basin, for example, was revealed to be a rift structure bounded by normal faults rather than a true structural basin. New anticlines and faults, as well as other trends, were discovered. Many of the features appear to be in the pre-Carboniferous basement since surface geology does not show sufficient structure in the younger beds to explain the observed anomalies.

The author's style of writing makes for somewhat laborious reading, probably because of his predilection for thoroughness in all discussions. Writing for a geological rather than a geophysical journal, he finds it desirable to make many general statements on gravity surveys which would not be necessary for readers trained as geophysicists. Even so, the reviewer recommends Mr. White's paper to all these who in the future may have occasion to write a case history for *Geophysics*.

MILTON B. DOBRIN

"Geophysikalische Probleme in Bayrisch-Swäbischen Donau-Raum" (Geophysical problems in southern Germany, south of the Danube) by H. Reich, *Erdöl und Kohle*, vol. 2, (1949) Pp. 81–87.

In most published reviews of geophysical work covering regions considerably larger than an average oil field, the gaps in geophysical control and in available geologic information are so substantial that it is impossible for the reader to get a well integrated picture showing the composite relationship between geophysical indications and geologic observations. It is therefore refreshing to find a review of a large area which is not merely a chronological and statistical listing of geophysical surveys but which is primarily an evaluation of their significance in terms of extensive geological studies.

As the geological setting of the foreland zone of the Alps is fairly well known, it is interesting to compare the established picture with geophysical findings. The geophysical surveys, most of them prewar, were generally not conducted for prospecting purposes but were mainly initiated in connection with academic research problems. The surveys included magnetic, gravitational and seismic methods. Dr. Reich, well known for his early experimental research in prospecting geophysics, has undertaken in this paper to correlate and map all the results on a regional scale.

The magnetic surveys were most complete. They show that the major magnetic anomalies are restricted to the marginal zones of the Bavarian Plateau. The lack of anomalies in the Flysch-Molasse Tertiary basin of the Bavarian uplands would indicate that the sedimentary cover is uniformly underlain by a granitic basement with no basic intrusives. The anomalies along the peripheries correlate with the covered extensions of the Bohemian Massive, but not with the extensive Miocene volcanic belt. This is established by the absence of magnetic anomalies in the extreme south of the Lake Constance area, where the volcanism is of the same type. Very significant also are the anomalies located along the German Austrian border in Tyrol, which are interpreted to be basic gabbroic masses located well below the surface and having no effect on the Alpine orogeny.

The gravity survey shows a marked alignment with the Alpine front. The contours of the Bouguer anomalies essentially parallel the ranges, the negative values increasing uniformly toward the south. This would indicate an increase of the Flysch-Molasse wedge toward the south. The presence of the Bohemian Massive and the Vosges-Black Forest complex shows up very well in the sharp decrease of the Bouguer anomalies in these areas.

The gravity results also cast light on the nature of the Nördlinger Ries, which has been considered a strongly cryptovolcanic area. The gravity low indicates a mass defect, which is explained on the assumption of a reduction of density in the sediments by repeated explosions which shattered the matrix. Positive anomalies in adjacent areas are explained by basic intrusions into the basement, these having been substantiated by magnetic surveys. Recent seismic investigations in this area, however, show that the crystalline mass is much closer to the surface than hitherto suspected. They also indicate that the large granite blocks which were thought to be erratic ejectamenta of an explosion are part of a well pronounced ring structure close to the surface.

In general the seismic surveys have covered only a very small portion of the area. There have been refraction surveys to trace the Molasse-Flysche tongue and this has been followed to a depth of 4000 ft. Reflection shooting was more successful in tracing the same contact farther south towards the Alps to a depth of 10,000 feet. The seismic results have further shown that the Mesozoic-Cenozoic boundary is not located along a well defined hinge line but that the transition is actually continuous.

MYRON T. KOZARY

"Isostasy—Extended" by Ross Gunn. *J. Geol.*, vol. 57 (1949) Pp. 263–279.

This article was prepared especially for presentation in a geological journal as a summary of the more detailed series of papers previously published by Gunn on "an extension of the principles of isostatic equilibrium." The earlier papers were published during the period 1937–1947 in the *Journal of the Franklin Institute* and in *Geophysics*.

The "extension" to the isostatic theory accounts for the role played by the strength of the earth's crust in supporting loads upon its surface. Starting with the Hayford-Bowie interpretation of isostasy, it is essentially an argument in favor of regional rather than local isostatic reductions. In the author's terminology, he supports the concept of "isobary" as opposed to "isostasy." In isobary the pressure at the isopiestic level is $M\bar{g}+S_v$ where $M\bar{g}$ may be called the Hayford-Bowie term and S_v the added vertical stress "imposed . . . by the finite strength of the lithosphere." Actually M is the mass per unit area and $\bar{g}$ the average value of gravity above the isopiestic level in any selected prism. The sum of the two terms is a constant for the case of isobaric equilibrium. Furthermore the expression maybe written in the approximate form,

$$M\bar{g}-\frac{g\Delta g}{2\pi\gamma}=\text{Constant}$$

where Δg is the principal term of the gravity anomaly and γ is the gravitational constant. In level regions the vertical stress term, S_v, is negligible and the isobaric case reduces to the special case of isostatic equilibrium. The author continues by pointing out that gravitational measurements in other regions would give an indication of vertical stress when compared to the measurements made in the level regions.

The gravity anomaly can also be computed from given geometrical distributions of load. Gunn presents figures of the deformations produced by a single vertical force and by long block loads in illustrating how one would derive the accompanying bending of the earth's crust. These figures include an important parameter, "b," in the abscissa term, bx, the horizontal distance in radians. "b" is characteristic of the ease of deformation of the crust and may be most conveniently remembered as the "reciprocal of the . . . approximate distance . . . for gross deformations to be attenuated." In magnitude, $1/b$ approximates 120 km. Figure1, showing the deformation for single vertical force, is important because the actual deformation for any load may be determined by the summation of the deformations caused by elementary loads each represented by a single vertical force. It is unfortunate that the ordinate of Figure 1 does not contain the parameter, F, the single vertical force, in some readily usable form. The figure illustrates the relative deformation of an unbroken crust as compared to a fractured crust, and the ordinate is apparently only a scale of relative deformation.

In Figure 2, the deformation of the crust for the long block loads of approximately 15, 30, 60, 120, and 240 kms. reveals that the 240 km. block is "submerged to a level that approaches the isostatic condition." Later in his article, the author shows that a block must be at least 330 km. wide to be supported 96% by the asthenopshere.

Throughout the history of the study of the crust from gravity observations, investigators have stressed the importance of a regional concept of compensation. Putnam, Glennie, and Vening Meinesz are notable examples. The important contribution of Gunn's papers is that they attack the problem of the bending of the crust from straightforward engineering principles and thereby yield an accurate and potentially useful method of determining the response of the lithosphere to added loads. Vening Meinesz (1931) used the same principle as Gunn for his regional compensation scheme, namely a

loaded elastic plate floating on a liquid layer. But Meinesz recognized a fundamental possible weakness of the hypothesis: that it does not represent the tectonic processes of the crust as well as it does the erosional and sedimentary processes. Gunn does not raise this question. Indeed he states that his *Sv* term of the isobaric expression is negligible in level regions. Apparently the two geophysicists represent opposing sides of the fundamental question of isostasy: namely, can isostatic forces initiate deformation? This question is of primary importance to the comparison of gravity anomalies between level and unstable regions, if the indicated vertical stresses are to be properly resolved.

The determinations of the "*b*" parameter, for example, may well be affected by this question since they are based on the dimensions of large topographic features, presumed created by loading. The Vening Meinesz school would claim that a loading factor could not be evaluated in an orogenic region where other vertical stresses are undoubtedly operating; yet Gunn maintains that the loading factor is negligible in level regions and must be obtained in an orogenic belt. Actually the values of "*b*" that Gunn has found are remarkably uniform. The value for a depositional feature (Nile delta), for example, 7.85×10^{-8} cm.$^{-1}$, is not greatly different from the value obtained from the Javanese deep-sea troughs, 8.6×10^{-8} cm.$^{-1}$.

NELSON C. STEENLAND

"Gravity Anomalies and the Nature of the Earth's Crust," by George Prior Woolard *Trans. Am. Geophy. Union*. Vol. 30, (1949). Pp. 189–201.

Prof. Woollard has provided a very useful thumb-nail review of the earth's gravity as it is known today by presenting in eleven pages data and comments for all gravity surveys of sufficient extent to be included in such a study.

Eleven combined isostatic gravity and topographic profiles of North America, the Pacific Ocean, and the Atlantic are shown initially. They are listed below with some of the author's pertinent comments.

AA—Southern Canada, from the Pacific to Atlantic Oceans. The conjecture is made that the area, formerly the center of the Pleistocene ice-cap, "will have to rise about another 4000 ft. to be in isostatic equilibrium."

BB—Minnesota Shield to Cape Cod. A "low" under the Appalachians "may reflect a residual 'root'. . . . "

CC—Phillippine Islands to the U.S.A. to Brittany. This is the most extensive and perhaps revealing profile. It's principal features are (1) the main Pacific area is in isostatic equilibrium, (2) the Atlantic area is characterized by marked positive anomalies in contrast to the Pacific area, and (3) the Pacific area west of the Andesite Line has an increasingly positive mean anomaly to the west.

DD—The North Atlantic, from Virginia to Spain.

EE—Southern United States. This area is essentially in isostatic equilibrium.

FF—New Orleans to Florida and across the Bahamas. A marked positive anomaly, not obviously explainable, lies in the Gulf of Mexico.

GG—Brownsville, Texas, to Africa.

HH—South Atlantic

II, JJ, KK—Deep-sea troughs in the East and West Indies.

Woollard concludes that the generalization, "the oceans are characterized by positive isostatic anomalies and the continents by negative . . . " is not justified by a study of the profiles.

He next presents his gravity and magnetic traverse across the United States. A standard density value of 2.67 was used in all the reductions. The profiles include an excellent demonstration of the equivalence between the isostatic and Bouguer regional corrections in an isostatically compensated area. The Green River Basin, Uncompaghre Uplift, and the Great Salt Desert were the only important exceptions.

The studies in eastern North America provided two interesting generalizations. First of all,

isolated gravity lows appear to correlate with granitic intrusives. Miller (1946) used these anomalies to make one of the few recorded quantitative estimates of the depth to the bottom of an igneous body. His minimum depth estimate was 10 km. The second generalization is an endeavor by Woollard to relate genetically the development of the geological and gravitational features of the eastern edge of the North American continent to those of the island arcs. He is led to do this by the occurrence of the anomalies as "positive and negative belts paralleling the geologic tectonic axes." There is undoubtedly a relationship but Woollard notes that the "continental mountain ranges face away from the sea" (by reason of the thrusts toward the land masses) whereas the "present island arcs . . . face away from the land toward the ocean." The reviewer would like to point out the possibility of removing this apparent conflict by changing the space relationships. For example, in the analogy to the Javanese arcs, the following space equivalences may exist:

Javanese	*American*
Borneo	Canadian Shield
Deltageosyncline of Umbgrove	Appalachian geosyncline
Volcanic island arcs (Java)	Off-shore volcanic arcs, long since destroyed but for which evidence remains in Pre-Cambrian and Paleozoic stratigraphy.

Gravity relationships in Asia are used for evidence that crustal warpings other than mountain ranges certainly exist. Bouguer anomalies in Europe are used to show that crustal thickening occurs in the upper granitic layer in contrast to the intermediate layer as in Southern California. Evidence is then presented that certain local features are not in isostatic equilibrium; the Rift Valleys of Africa, and the island arcs' negative belts being examples.

From this abundance of material the author concludes that the crust

(1) yields to large (ice-caps) but not local (volcanic islands) loads.
(2) varies in thickness to accommodate large topographic irregularities.
(3) yields to accumulative loads (sedimentary basins).
(4) fails by shear and flexure along lines of weakness (continental boundaries).
(5) varies in apparent thickness over broad areas in a random manner.
(6) has a heterogeneous lithology.

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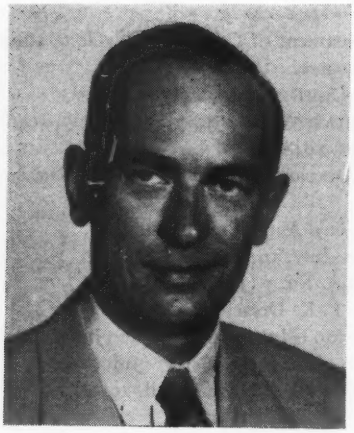
CONTRIBUTORS



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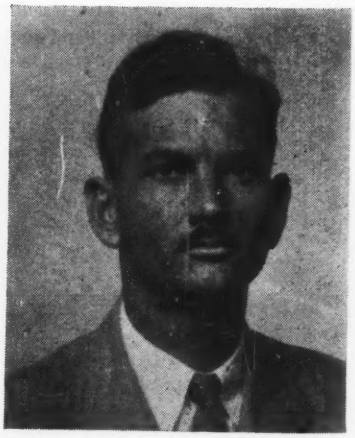

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A. BELLUIGI

A. BELLUIGI is a member of the Faculty of Engineering of Instituto di Geofisica Mineraria, Universita di Cagliari, in Cagliari, Italy. He holds a doctor's degree in physics, and since 1924 he has specialized in applied geophysics.

In 1927 he organized and directed for a number of years the geophysical operations of the A.G.I.P. (General Italian Petroleum Firm) and of the A.I.P.A. (Italian Petroleum Firm in Albania). He located the extensive deposit structures buried in the Padana Plains, a discovery accomplished by first employing gravimeter methods. These gave the first inklings of the existence of petroleum in Italy. The resumption of this work is being accomplished by the employment of seismic methods accompanied by a series of gravimeter studies. Other petroleum fields have been located in the following regions: Marche, Abruzzi, Valle Latina and Sicily in Italy; Albania and Abyssinia.

Since 1933 he has taken part in many studies based on the theory and construction of electric coring apparatus. In addition, he has worked on applications of the Sismatic and Eltran theories. In the department of metallic minerals he collaborated with the A.M.M.I., The Italian Geological Bureau, the General Government A.O.I. and with many associations on Mineralogy. Also he worked toward the perfection of the geoelectric methods on continuous and alternate current (low frequency).

Recently he introduced electrical methods in the search for minerals by the adoption of new devices such as the "Mind" and the "Trib." These methods rendered possible the detection of small amounts of mineral deposits along the pilasters in mining tunnels.

Dr. Belluigi is an Active Member of the Society of Exploration Geophysicists.

In addition, references are cited to earlier issues for the biographies of: E. A. Eckhardt, Vol. XIII, No. 4 (October, 1948); Hart Brown, Vol. VIII, No. 4 (October, 1943); Roland G. Henderson, Vol. XIII, No. 3 (July, 1948); Isidore Zietz, Vol. XIII, No. 3 (July, 1948).

SOCIETY ROUND TABLE

NOMINEES FOR 1950–51 EXECUTIVE COMMITTEE

The following brief biographical sketches are presented to acquaint members of the Society with nominees appearing on the official ballot which will be mailed to all voting members at a later date.

FOR PRESIDENT

MAURICE EWING

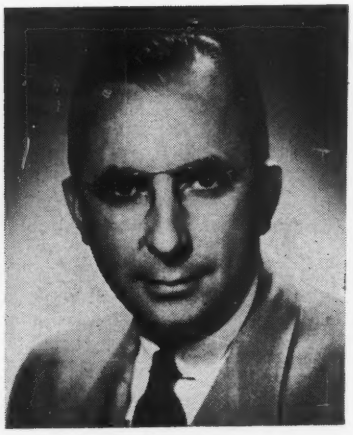
GEORGE E. WAGONER

MAURICE EWING received his B.A. (1926), M.A. (1927), and Ph.D. (1931) degrees from the Rice Institute, Houston, Texas. He was on the faculty of Lehigh University from 1930 to 1944, and is now Professor of Geology at Columbia University, and Research Associate of the Woods Hole Oceanographic Institution. His research, the geophysical investigation of the structure of continents and ocean basins, includes extensive measurements of gravity at sea, seismic surveys of the Atlantic continental shelf and ocean basin, wartime work on underwater sound transmission, underwater photography, oceanographic instrumentation, and exploration of the Mid-Atlantic Ridge.

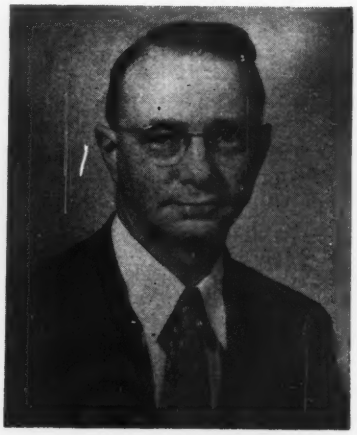
GEORGE E. WAGONER received the degree of Geological Engineer from Colorado School of Mines in 1928. He was employed as a geologist and geophysicist by John H. Wilson, consulting geologist and geophysicist of Goldon, Colorado, from June, 1928 to May, 1930. He was employed by Humble Oil and Refining Company from 1930 to 1934 as a torsion balance observer, seismograph computer and seismograph party chief. In 1934, he was loaned to The Carter Oil Company as an assistant to the chief geophysicist. In 1935 he was transferred to The Carter Oil Company as supervisor of geophysical operations. In 1936 he was transferred to the Standard Oil Company of Louisiana as chief geophysicist. In 1937 he returned to The Carter Oil Company as assistant chief geophysicist in charge of geophysical exploration. In August, 1946 he was appointed manager of exploration for the Southern Division of The Carter Oil Company, Shreveport, Louisiana.

He is a member of the Society of Exploration Geophysicists (Secretary-Treasurer, 1945–1946, chairman of the Public Relations Committee 1947–1949, member of the Committee on Constitution and Bylaws 1947–1948, chairman of the Shreveport Regional Program Committee 1947–1948), Ark-La-Tex Geophysical Society (President 1947–1948 and member of the executive committee 1948–1949), American Association of Petroleum Geologists and the Shreveport Geological Society. At present he is serving as Vice President and chairman of the Program and Arrangements Committee of Society of Exploration Geophysicists.

FOR VICE-PRESIDENT



DAYTON H. CLEWELL



SIGMUND HAMMER

DAYTON H. CLEWELL received his B.S. degree in Physics in 1933 and his Ph.D. degree in Physics in 1936, both from the Massachusetts Institute of Technology. He was employed by the C. K. Williams Company of Easton, Pa., from 1935 to 1938 as a physicist working on optical properties of paints and pigments and developing instruments to measure brightness and color of pigments. From 1938 to 1942 he was employed by the Geophysical Department of the Magnolia Petroleum Company and was in charge of the development of Gravity Meters. In 1942 he was transferred to the Magnolia Petroleum Company, Field Research Laboratories as supervisor of Physical Research where problems in seismic, gravity, geochemical, and electrical prospecting were investigated, as well as problems in catalysis. From 1946 to the present time, he has been Asst. Director of Magnolia Petroleum Company, Field Research Laboratories and Supervisor of Exploration Research. He is the author of several papers in the field of experimental physics and geophysics. He is a member of the A.I.M.E., A.P.I., American Physical Society, American Geophysical Union, American Institute of Electrical Engineers, American Association of Petroleum Geologists, Institute of Radio Engineers, Sigma Xi, and Society of Exploration Geophysicists.

SIGMUND HAMMER was born August 13, 1901, in Webster, South Dakota where his father was for many years a Norwegian-Lutheran Minister. He received the B.A. degree at St. Olaf College, Northfield, Minnesota, in 1924. As a student assistant in the Physics Department there he participated in the design, construction, and operation of the college broadcasting station, WCAL, which is still in operation. From 1924 until 1929 he was teaching fellow and graduate student in the Physics Department at the University of Minnesota where he received the Ph.D. degree (Major: Physics; Minor: Mathematics). During this period, summers were spent in employment as radio operator on board ship, research assistant and Radium Technician in the University Hospital.

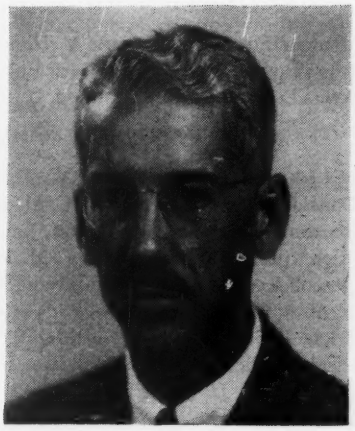
Dr. Hammer has been employed in the Gravity Interpretation Section of the Geophysics Division of the Gulf Research & Development Company, Pittsburgh, Pennsylvania, since 1929, and has had charge of the section since 1946. He also is a Lecturer in Geology at the University of Pittsburgh, where he teaches a course in Geophysical Prospecting. He has published several technical papers on the gravitational field of the earth, Geophysical Prospecting, and Geophysical Applications of the Statistical Theory of Errors.

Dr. Hammer is a member of the American Physical Society, Physical Society of Pittsburgh (Secretary-Treasurer 1941, Vice President 1942, President 1943), American Association for the

Advancement of Science, Pennsylvania Academy of Science, Sigma Xi, American Association of Petroleum Geologists, American Geophysical Union (member, Special Committee on the Geophysical and Geological Study of the Continents), and the Society of Exploration Geophysicists (chairman, Regional Program Committee for the Eastern States; General Chairman for Eastern Regional Meeting in Pittsburgh in 1947).

FOR SECRETARY-TREASURER

FRANCIS F. CAMPBELL



WILLIAM HENRY COURTIER

FRANCIS F. CAMPBELL graduated from Haverford College with a B.S. degree in 1926, and from the Graduate School of Business Administration, Harvard University, with a M.B.A. degree in 1931. He began in geophysics as a computer on a Geophysical Research Corporation refraction seismograph party in 1926. Since 1933 he has been with Amerada Petroleum Corporation as party chief and geophysical supervisor. Mr. Campbell is a member of the Boards of Trustees of All Souls Unitarian Church and the Y.M.C.A. in Tulsa. In 1947 he was elected secretary-treasurer of the Geophysical Society of Tulsa and in 1948 first vice president. He has been a member of the Society of Exploration Geophysicists since 1936 and is currently serving the society as Chairman of the Distinguished Lecture Committee. He is a member of the Tulsa Geological Society and the American Association of Petroleum Geologists.

WILLIAM HENRY COURTIER received his B.S. degree in Geology and Civil Engineering from Denison University, Granville, Ohio, in 1926, and in 1928 he received a M.S. degree in Geology and Geophysics from Colorado School of Mines. From May, 1928 through April, 1931 he was assistant geologist for The Midwest Refining Company in Denver, Colorado. He entered the graduate school of the University of Kansas in 1931, serving as assistant instructor in Geology and received the Ph.D. degree (Geology) in June, 1934.

In May, 1934 he accepted the position of junior geologist in the Fuels Section of the United States Geological Survey. He left that position to join Phillips Petroleum Company in August, 1935 as computer, seismic. Promotion to party chief, seismic in June, 1936 and to supervisor, seismic in February, 1937 led in January, 1938 to his present position as assistant chief geophysicist for the company in Bartlesville, Oklahoma.

He is a member of the Geophysical Society of Tulsa, Society of Exploration Geophysicists, American Geophysical Union, American Association of Petroleum Geologists and Sigma Xi. He served as S.E.G. District Representative from the Geophysical Society of Tulsa for 1948–1949.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the president within thirty days. (Names of references appear in parentheses after the name of each nominee.)

ACTIVE

Edmund Borys (Hart Brown, Eugene McDermott, Cecil H. Green)
Robert Briley Haynes, Jr. (R. J. St. Germain, John L. Bible, K. G. McCann)
Rodney Ayers Lowery (D. P. Carlton, H. G. Patrick, J. E. LaRue)

ASSOCIATE

Mohammed Ishaque Chowdri (Eugene W. Frowe, Mohammed Ibrahim Chowdri)
Marvin Donald Gontarek (Jack Oden, C. M. Moore, Jr., K. E. Burg)
Thomas Barron Howes (George Augustat, James H. Todd, Joseph W. Northrop III)
Edward Rice Kinsley (J. L. Stephens, C. M. Moore, Jr., C. H. Green)
Herman Joseph Koch (Cecil H. Green, Virgil Teufel, Robert Dunlap, Jr.)
Deloard Renfrew Mabry (R. C. Cole, G. W. Carr, R. M. Rogers)
Samuel Bright Randle, Jr. (R. C. Cole, G. W. Carr, R. M. Rogers)
Edmond Seidner (Lic. Miguel Prodo Solares, non-member, Ben F. Rummerfield, T. A. Manhart)
Edward E. Simmons, Jr. (F. C. Lindrall, C. P. Walker, A. N. Campbell)

TRANSFER TO ASSOCIATE

Henry G. McCleary

STUDENT MEMBERS ELECTED

The following students have been elected to student membership in the Society in accordance with Article III, Section 5, of the Bylaws.

Charles M. Baker, *University of Texas*
Curtis R. Bernard, *University of Texas*
C. Walter Faessler, *California Institute of Technology*
Charles R. Jones, *University of Texas*
Archie T. Long, *University of Texas*
Stephen W. Miller, *Stanford University*
John L. Proctor, *University of Texas*
Leo N. Romer, *University of Utah*
Jackie D. Wallner, *University of Texas*

MEETINGS OF THE LOCAL SECTIONS

SOCIETY OF EXPLORATION GEOPHYSICISTS, HOUSTON SECTION

December 1, 1948

Oceanography and Some Relations to Geophysical Prospecting, C. O'D. Iselin, Director, Woods Hole Oceanographic Institution.

January 28, 1949

Secondary Refractions, M. M. Slotnick, Humble Oil & Refining Co.

February 18, 1949

Weathered Layer in the Mississippi Valley, Harold N. Fisk, Humble Oil & Refining Co.

May 27, 1949 (Annual Dinner Meeting)

The Society held its annual meeting in the Ben Milam Hotel, with an attendance of 116 members and guests. A report on the progress of meetings with the Federal Communications Commis-

sion relative to frequency allocation for geophysical services was given by Otis B. Hocker and Gregg F. McReynolds. The annual report of the Treasurer was given by H. E. Banta.

Presentation of an honorary membership to Burton McCollum was made by Walter J. Osterhoudt, past president of the Houston Section. To complete the citation, E. A. Eckhardt and J. C. Karcher, who were associated with Mr. McCollum in the pioneer days of geophysical development, spoke briefly on their early experiences, both in the Bureau of Standards and in experimental exploration work. President Roy Lay then made the formal presentation of a beautiful scroll to Mr. McCollum who delivered an acceptance speech in which he reviewed the past progress of exploration geophysics and suggested continuation of experimental work toward greater resolving powers.

As retiring President, Mr. Lay announced the election of officers for the year 1949–1950 as follows: J. C. Pollard, President; Derry H. Gardner, First Vice President; R. F. Bennett, Second Vice President; Wm. H. Gibson, Secretary; and C. H. Broussard, Treasurer.

The outgoing officers presented the new officers with projection equipment for the use of the Society in future technical meetings.

This being the final meeting of the fiscal year, it was announced that the next regular meeting of the Society will be held in September, 1949.

R. F. BENNETT
Secretary

ARK-LA-TEX GEOPHYSICAL SOCIETY, SHREVEPORT, LOUISIANA

June 3, 1949 (Annual Meeting)

The final meeting of the 1948–1949 fiscal year was held at the 40-8 Club on Cross Lake near Shreveport. About 35 members attended the meeting conducted by Harry M. Buchner, retiring President. Officers of the S.E.G. present were: Cecil H. Green, Past President; Kenneth E. Burg, Secretary-Treasurer; and George E. Wagoner of Shreveport, Vice President. Also introduced with an expression of thanks for their outstanding efforts were R. M. Wilson and J. R. Walker, representatives to the S.E.G., B. B. Burroughs, Publicity Chairman, Richard Brewer, member of the S.E.G. Radio Frequency Allocations Committee and chairman of the Barbecue Committee, and L. H. Wells, Chairman of the Geophysical Code Committee.

Mr. Green reported the progress toward organization of a joint regional convention in Dallas this fall and extended an invitation to the Ark-La-Tex Geophysical Society to participate in the meeting. The Secretary-Treasurer announced a paid-up membership of 66 and reported a tentative, pre-final meeting balance of $130.58 in the treasury, expenditures for the year having totaled $63.14. Mr. Fischer reported that papers have been obtained to fill completely the time allotted to the Society at the Biloxi, Mississippi meeting in the fall.

By unaminous vote the Society adopted the changes in the constitution recommended by W. M. Rust, Jr., allowing the Ark-La-Tex Geophysical Society to become affiliated with the Society of Exploration Geophysicists.

The following officers for the year 1949–1950 were elected by acclamation: Carl L. Bryan, President; Richard Brewer, Vice President; Jackson Young, Secretary-Treasurer. The new officers took charge and the meeting was adjourned in favor of refreshments and entertainment.

CARL L. BRYAN
Secretary-Treasurer

GEOPHYSICAL SOCIETY OF TULSA

May 12, 1949 (Annual Meeting)

The annual meeting of the Society was held on Thursday evening in Lorton Hall on the University of Tulsa campus. A. B. Bryan, retiring President, presided. Over sixty members and guests were present.

In the absence of the Secretary-Treasurer, V. L. Jones submitted the membership and financial reports of the Society for the year 1948–1949, after which the following officers for the year 1949–1950 were elected: W. T. Born, President; E. M. McNatt, First Vice President; N. J. Christie, Second Vice President; and N. R. Sparks, Secretary-Treasurer.

Mr. Born introduced the speaker of the evening, Lorenz Shock, National Geophysical Company, Inc., of Dallas, Texas, who presented his paper, "Progressive Detonation of Multiple Charges in a Single Seismic Shot." Mr. Shock discussed the relative efficiencies of various sizes of explosive charges for generation of seismic energy and a method of progressive detonation so that energy from individual charges will arrive simultaneously at the recording position. Results were presented for both horizontal and vertical spacings of individual charges and possible application in reflection and refraction shooting were discussed.

G. D. LAMBERT
Secretary-Treasurer

ANNOUNCEMENTS

GERMAN MINING JOURNALS

Publication of *Zeitschrift fuer Metallkunde* and *Zeitschrift fuer Erzbergbau & Metallhuettenwesen* has been resumed, according to the publishers, Dr. Riederer—Verlag G.m.b.H., Box 447, Stuttgart S, Germany.

These journals contain reports from German and foreign research institutions and laboratories, and are read by those circles in Germany which are interested in either the physics and chemistry of metals and their alloys, their production, manufacture or testing, or in the mining and smelting industries. Sample copies will be furnished to any organizations interested in these subjects upon request to the publishers.

CALGARY GEOPHYSICISTS TO ORGANIZE

At an informal luncheon in Calgary on April 30, 1949, eleven geophysicists met to hear L. L. Nettleton, past president of S.E.G., who outlined the advantages of organizing a local section in that area. Present were: L. I. Brockway, Gulf Oil Co.; H. M. Fritz, Shell Oil Co., Inc.; H. M. Houghton, Amerada Petroleum Corp.; Ed Kolb, Western Canada Petroleum Association; J. H. McKeever, Stanolind Oil & Gas Co.; F. M. Mitcham, Barnsdall Oil Co.; C. M. Moore, Jr., Geophysical Service, Inc.; W. A. Phares, United Geophysical Co. of Canada; K. A. Robertson, United Geophysical Co. of Canada; T. Rozsa, Shell Oil Co., Inc.; and A. L. Winsler, Stanolind Oil & Gas Co. Considerable interest was shown by those present, and it was decided to meet again in the Pallister Hotel on June 2, 1949, immediately after the meeting of the Geophysical Section of the Western Canada Petroleum Association dealing with general operating problems.

Much of the ground work for a Canadian section was performed by Wayne A. Phares, who took the time to contact several geophysicists in the Calgary area and planned the first two meetings. At the June 2nd meeting it was decided that C. M. Moore, Jr., would handle the immediate details as far as organizing the section, since those present agreed on the formation of a local section in Calgary, Alberta, Canada.

ENGINEERS SELECTED URGED TO CO-OPERATE

To provide source material for a who's who in engineering research, development and other scientific operations for use by the National Military Establishment, the Engineers Joint Council acting through The American Society of Mechanical Engineers has accepted the task of providing the Office of Naval Research with the names, addresses, ages, and details of professional and scientific qualifications of 100,000 key engineers in all branches of American engineering.

The source file of key engineering personnel thus obtained will provide a valuable tool for industrial mobilization for war production and national defense in time of emergency. Its use will

diminish disturbances of the national economy, organization of industry and the personal welfare of engineers, and provide a means by which national resources of technical personnel can be ascertained. The file will also point up weak spots which should be strengthened by education, training and other means. As a national asset the body of facts will be available to private industrial, educational, and professional-society planning groups, and for other legitimate purposes.

A four-page questionnaire has been mailed to 100,000 engineers holding the grade of member or higher in 18 national professional engineering societies. The returns will be collected by the ASME and turned over to the Office of Naval Research of the National Military Establishment for classification.

The project is the result of a conference held in Washington, D. C., last fall attended by EJC representatives and many other engineering agencies, at which was discussed the need for a list of 25,000 key engineers working in research, development and other scientific projects who could be called in on a full or part-time basis to work on the broad scientific programs of the National Military Establishment. The task of collecting personal and professional data fell to the EJC as the largest joint agency of the engineering profession. ASME assumed administration of the project as contracting agent of the EJC.

The Engineers Joint Council points out that this is not just another questionnaire, but one sent to engineers selected from the upper echelon of the profession. The data sought is not intended for general government use but will go directly to the engineering agencies of the National Military Establishment, who will make direct use of it. As the questionnaire will provide the key to opportunity to professional and patriotic service, engineers selected to receive it are urged to give it serious attention and to answer all questions fully.

A.P.I. HANDBOOK REVISED

An improved, up-to-date edition of "Your Industry and Mine," an excellent handbook for employes of the oil industry, has been published by the Department of Information of the American Petroleum Institute.

Well illustrated with sketches and drawings, the booklet was written primarily for the hundreds of thousands of men and women who work in oil. In simple, non-technical language, it supplies them with a thumbnail understanding of the industry, its history and the progressive policies and operations which have made it one of the keystones of the nation's economy.

The current edition is the third one, and brings the booklet up to the 1949 level. It is being made available to the industry's 34,000 companies at cost, for distribution to their employes. Orders may be placed with J. A. McNally at the American Petroleum Institute, 50 West 50th Street, New York 20, New York. Discounts are available on bulk orders.

1949 ISSUES NEEDED FOR NEW MEMBERS

The unforseen rise in membership of the Society, and the rapid increase in subscriptions to *Geophysics*, have so far exceeded expectations for the year that the number of copies of the Journal printed has proven inadequate. During 1948 the Society published 2500 copies of each issue. This number provided the issues which were sent to all new members elected during that year, and left a backlog of sufficient number to supply future orders for back issues. The print order was increased at the beginning of this year to 2700 copies of each issue to provide for an anticipated 200 new members. It was expected that the number of subscriptions would remain at 250.

The Society has elected a total of 488 new members who are entitled to receive all issues of the Journal for the year. Of these, 346 whose names were published in the October (1948), January and April (1949) issues will receive their copies. There are not enough copies of the January, April and July issues on hand to supply the 142 applicants published in the July number. The twelve applicants whose names appear in this issue will be notified concerning their election some time in November. Those who are elected will receive statements for 1950 membership dues, and upon payment will receive the Journal beginning January, 1950. In addition to doubling the rate of increase in member-

ship, the Society has filled orders for 500 subscriptions which began in January of this year, doubling the total number of subscribers.

Encouraging though it is that the Society is growing, there remains the problem of providing its services to the new members. The cost of reprinting the missing numbers of *Geophysics* might be prohibitive, therefore the business manager is appealing to the individual members. Those members and subscribers who have any or all the first three numbers of 1949, and who would be willing to part with them, can relieve the situation by forwarding unneeded copies to the Business Office (Box 1614, Tulsa 1, Oklahoma). They will be reimbursed the costs of shipping at the rate of 25¢ per copy. All issues received will be distributed immediately to the newly elected members, and any surplus copies will be returned promptly to the donors. Members are requested to consult the list of applicants appearing on pages 440–442 in July 1949 *Geophysics*. If any of these new members are nearby, please share your copies.

Through establishment of an improved control system, it is hoped that this type of emergency can be avoided in the future.

COLIN C. CAMPBELL, *Business Manager*

NATIONAL PETROLEUM COUNCIL QUESTIONNAIRE

W. W. Vandeveer, Chairman of a special committee appointed by the National Petroleum Council to make a study of the manpower needs of the Petroleum Industry, announced today that his group has completed work on a questionnaire. More than 25,000 copies of the questionnaire have been mailed out by the headquarters of the National Petroleum Council in Washington to every company in the industry.

The survey forms have been divided by the Committee into five separate classifications: exploration and production, manufacturing, pipe line transportation, and supplies, shipping and distribution and general management. Companies receiving the questionnaire are asked to indicate the total number of personnel employed by the company in each of these general classifications. In addition, the companies are asked to indicate the total number of male and female employees, the number of employees in the Armed Forces reserves or National Guard, and the number of employees of draft age (under 35). They will also indicate the number of men in positions which require long training or experience so that replacements are not readily available.

The replies to these questionnaires will be consolidated by the Manpower Committee and will be turned over by the Committee for the use of the National Security Resources Board, which is making a study of the manpower needs of important industries in the event of another war.

Mr. Vandeveer said that the Committee has tried to reach every company in the petroleum industry, through the use of various directory and trade association mailing lists. Any company which has not received one of the Committee's questionnaires should write to James V. Brown, Secretary-Treasurer of the National Petroleum Council, Suite 601-1625 K Street, N.W., Washington 6, D. C.

PERSONAL ITEMS

ALBERT F. CLINE, 44, of Tulsa, Oklahoma, died June 22, 1949 in Oakley, Kansas, while working with a field crew. He suffered a heart attack.

Mr. Cline was field supervisor for Frost Geophysical Corp. at the time of his death. He had been with that company since 1943, and had been an active member of the Society since 1945.

REESE H. TUCKER is now chief geologist for Cities Service Oil Co., Bartlesville, Oklahoma, after serving as mamager of geophysics for the company since June, 1948. Mr. Tucker has been an active member of the Society since 1943.

WILLIAM GREGG BLANCHARD, of Coral Gables, Florida, is rapidly recovering from a coronary thrombosis suffered last October first. Our members will remember Mr. Blanchard as the father and procurer of the so-called "Blanchard Concession," a seven million acre holding of State Sovereignty lands off the tip of southern Florida, and on which the Benedum interests and Gulf Oil Company have been drilling.

R. W. DUDLEY, resigned his position with the Pure Oil Company January 1, 1949 to become Seismologist for Cummins, Berger and Pishny, 1603 Commercial Standard Building, Ft. Worth 2, Texas. Mr. Dudley's company affiliation is listed wrong in the April membership list.

H. M. HOUGHTON, geophysical supervisor in charge of the Canadian program of Amerada Petroleum Corporation, suffered a fall which resulted in a serious brain injury early in May of 1949. He has recovered well, but has been undergoing a series of operations in an effort to regain the use of one eye which was affected. Mr. Houghton has been an active member of the Society since 1936, and recently took an active part in the organization of its Calgary local section. JAMES S. HOPKINS, formerly party chief for Amerada and an active member of the Society since 1939, has been transferred to Calgary as assistant to Mr. Houghton. Their address is 513 Eighth Avenue West, Calgary, Alta., Canada.

GERALD A. BURTON has been promoted from seismologist at Casper, Wyoming to area geophysicist in New Orleans for Shell Oil Company, Inc.

WILLIAM A. MATTHEWS, formerly geophysical supervisor, Rocky Mountain division, Stanolind Oil & Gas Co., has been transferred to Calgary, Alta., where he assumes his new position as division geophysical supervisor for the company's foreign exploration department, Canadian division.

H. M. HORTON has resigned his position as manager of exploration for The Superior Oil Co. of Venezuela and returned to Mount Carmel, Ill., as an independent operator. His mailing address is Box 125.

HENRY SALVATORI, President of Western Geophysical Company, has been named vice president of the recently established Los Angeles Petroleum Club. Quarters of the club were opened on the third floor of the Biltmore Hotel on August 1.

P. L. TERRASSON is now assistant seismologist for Shell Oil Co., Inc., at Corpus Christi, Texas. He was formerly located at Barrhead, Alta., Canada.

M. B. RAMACHANDRA RAO has been appointed geophysicist for the Geological Survey of India, with headquarters at 27, Chowringhee Rd., Calcutta 13, India.

A. P. CRARY, formerly with United Geophysical Company, Bahrein Island, Persian Gulf, is now with the USAF Research Group. He may be addressed in care of Air Force Cambridge Research Laboratories, 230 Albany Street, Cambridge 39, Massachusetts.

CHARLES E. BUFFUM has been promoted to research-group supervisor, RALPH E. HARTLINE has been named research-group supervisor, and HAROLD M. LANG has become instrument-shop supervisor in the Stanolind Oil & Gas Company research laboratory, Tulsa.

SPECIAL REGIONAL MEETING NOTICES

DALLAS REGIONAL MEETING

A regional exploration meeting of the Society of Exploration Geophysicists will be held at the Adolphus Hotel, Dallas, Texas, on November 17 and 18, 1949. Sponsors will be the Dallas Geophysical Society, the Fort Worth Geophysical Society, the Ark-La-Tex Geophysical Society (Shreveport) and the Geophysical Society of Tulsa. Registration will commence the afternoon of November 16. Members planning to attend are requested to make hotel reservations directly with the hotels of their choice.

Tentative plans include papers on the following subjects:

GEOPHYSICAL CASE HISTORIES.....4 to 5 papers

NEW GEOPHYSICAL INSTRUMENTS AND TECHNIQUES.....3 to 4 papers

1. One Boat Seismic Unit for Water Exploration
2. Radar Altimeter
3. Application of Electric Logging to Ground-Water Exploration

GEOLOGY AND GEOPHYSICS OF REEF STRUCTURES.....1 full day

ANNUAL FALL MEETING OF PACIFIC COAST SECTION

The Pacific Coast Section of the Society of Exploration Geophysicists will meet concurrently with the annual Fall regional meeting of A.A.P.G. and S.E.P.M. at the Ambassador Hotel in Los Angeles on the 17th and 18th of November.

Papers of a technical or semi-technical nature of interest primarily to geophysicists will be heard from 9:30 to 11:30 the morning of the 17th. Papers of general interest will be heard during the afternoon of the 17th, possibly in joint session with the geologists and paleontologists. On Friday, November 18, the geophysicists will hold a luncheon meeting for the purpose of handling various items of business.

A symposium on California Off-Shore Geophysical Prospecting Problems is being considered for the afternoon session of the 17th. Three papers on this subject have been committed.

Dr. Beno Gutenberg, California Institute of Technology, has consented to present a report on the evidence he has accumulated over the years regarding the systematic aspects of faulting in Southern California.

The afternoon session has been planned to provide time for full and adequate discussion of papers. All authors of papers are requested to submit, prior to October 10, abstracts of sufficient completeness so that a reader can come to the meeting with intelligent discussion and questions already in mind. These abstracts will be reproduced and distributed prior to the meeting date.

Members having interesting material to present at this meeting are requested to advise Dr. C. Hewitt Dix, California Institute of Technology, Pasadena 4, California.

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In order that this Index to Volume XIV may serve as a supplement to the Cumulative Index covering all publications of the Society from 1931 through 1946, it has been arranged in the same order as that adopted for use in the Cumulative Index.

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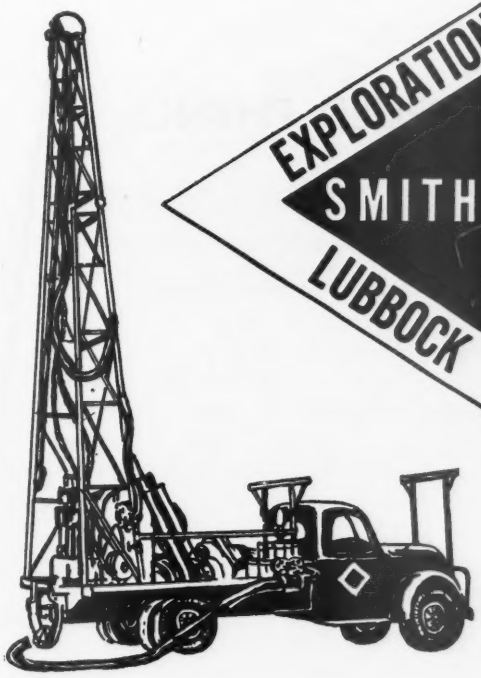

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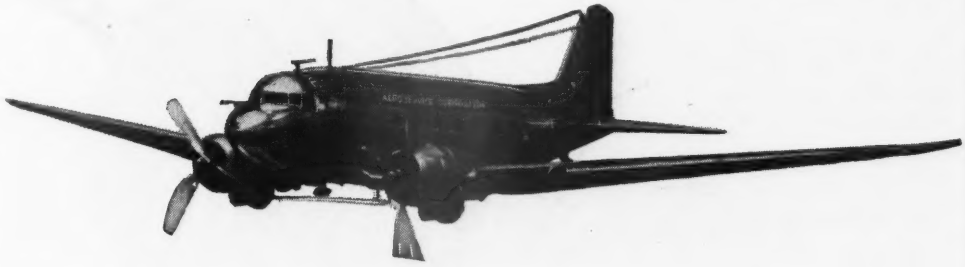

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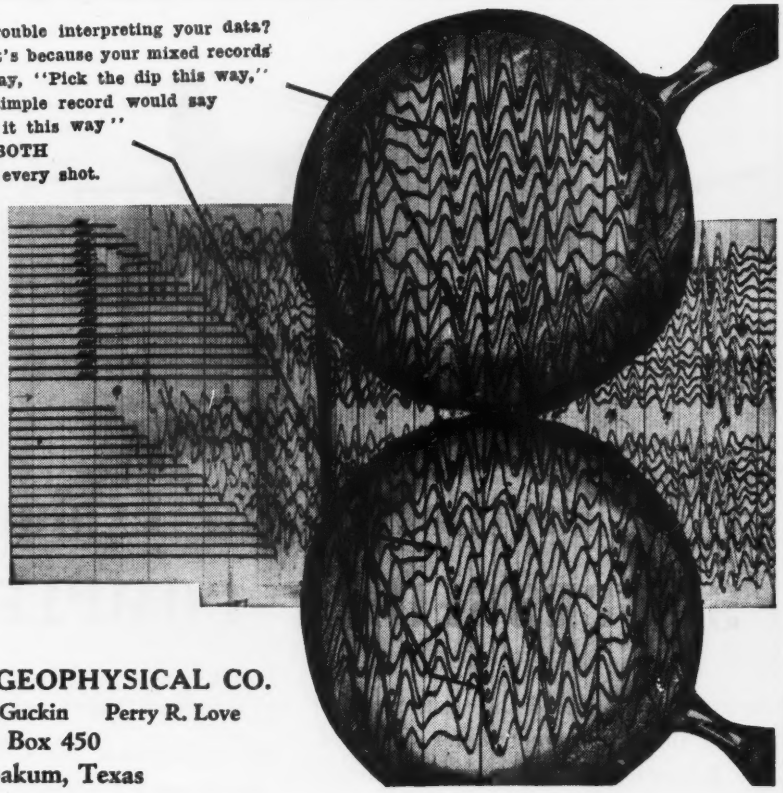

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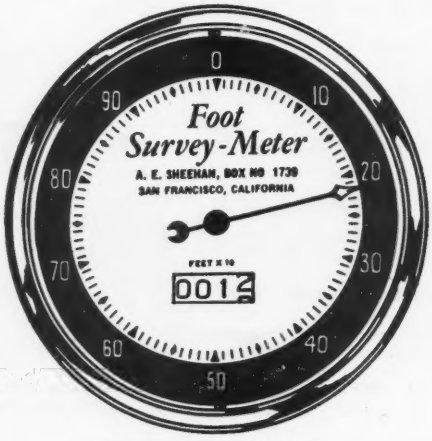

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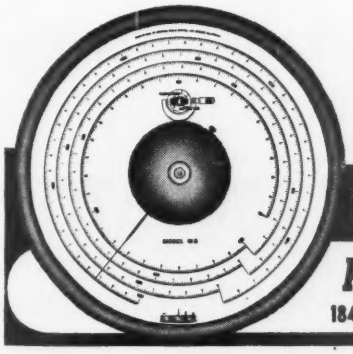

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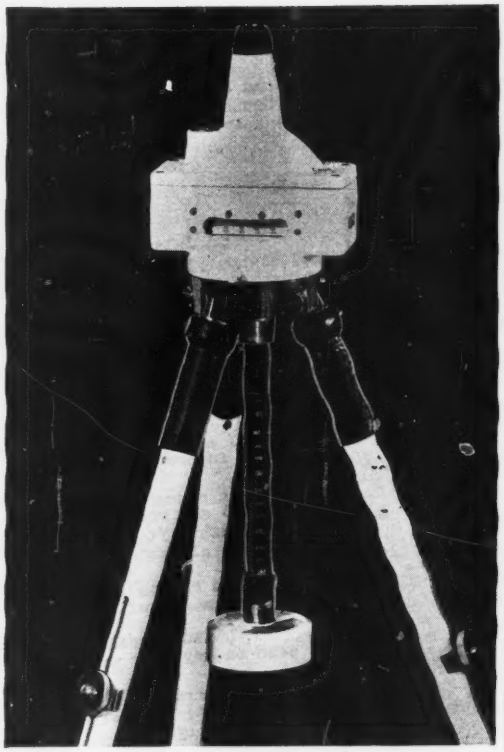

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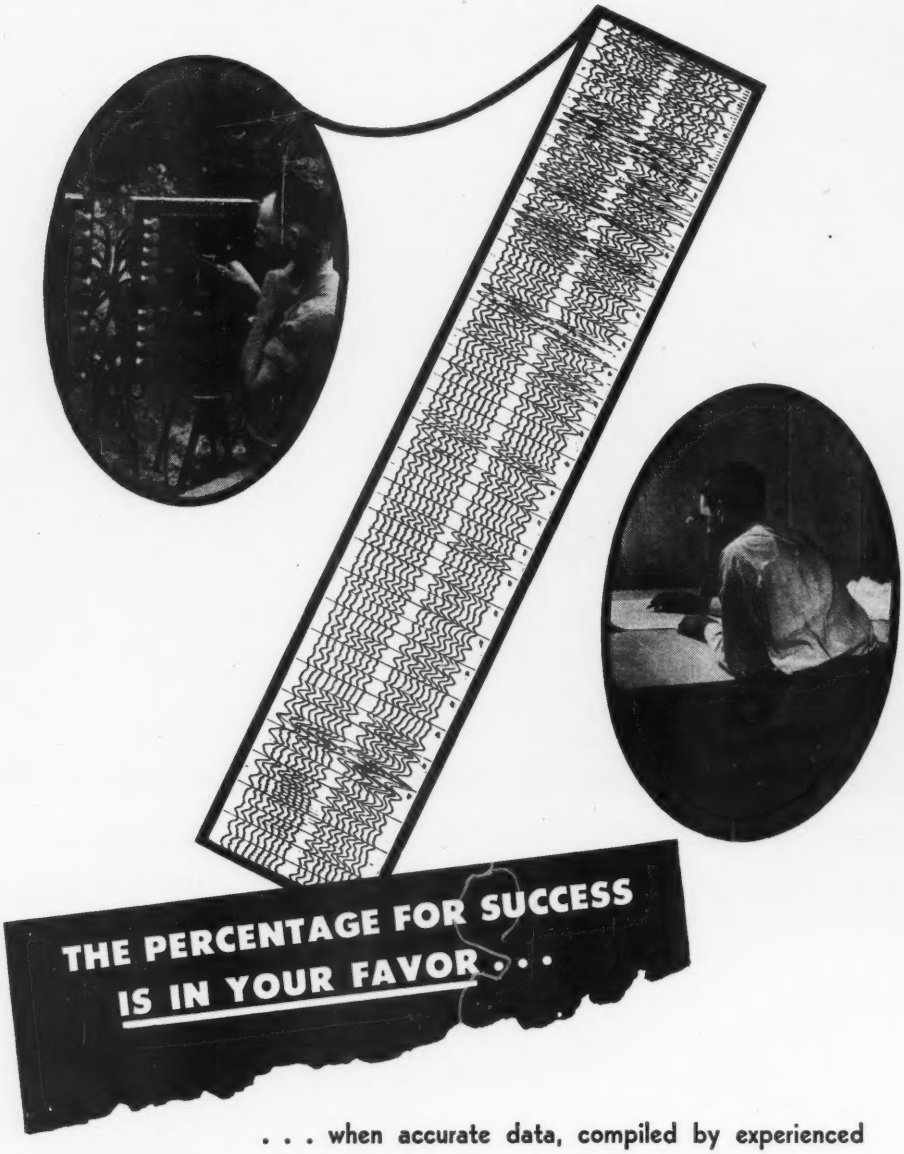

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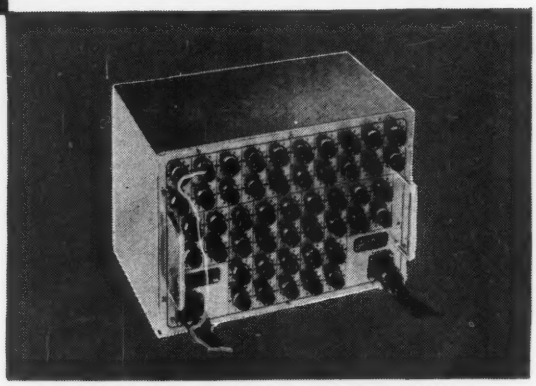

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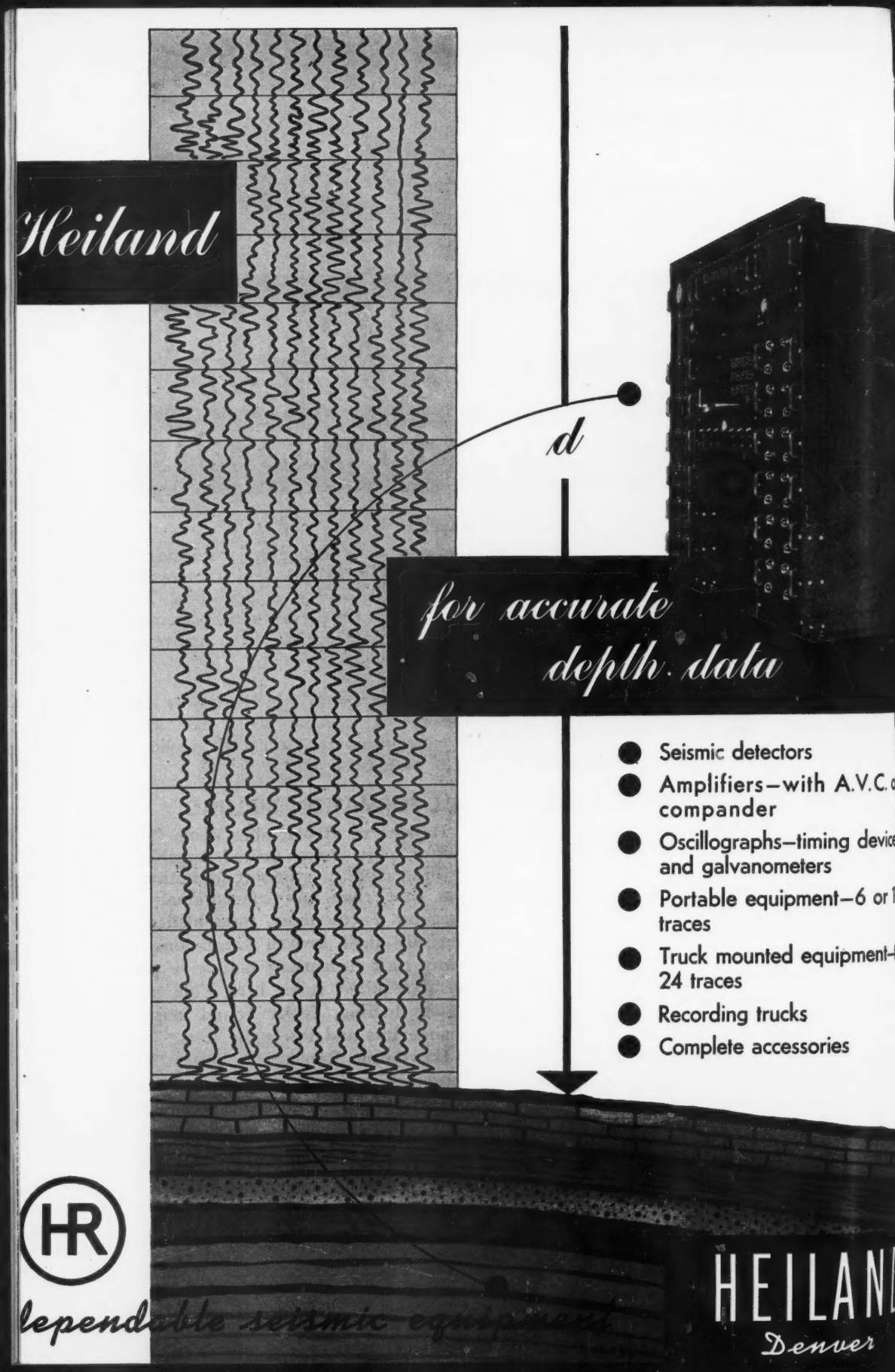
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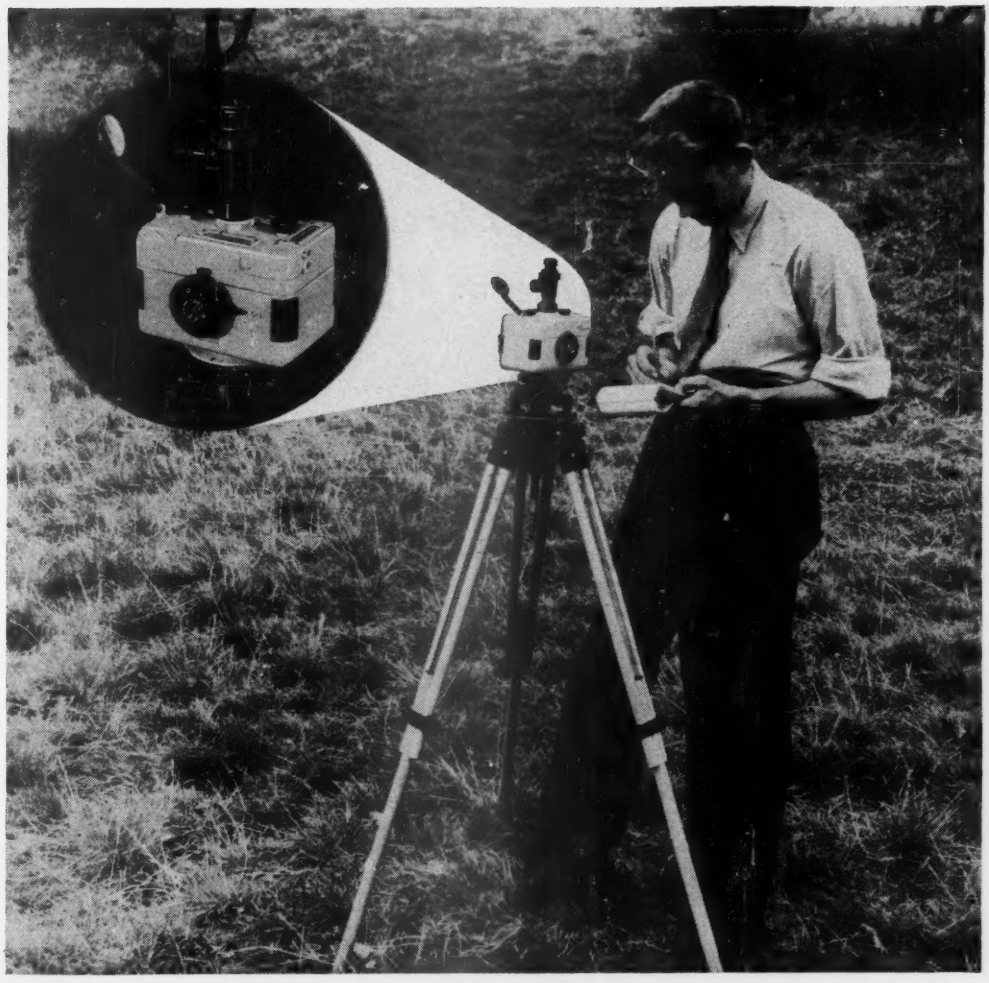

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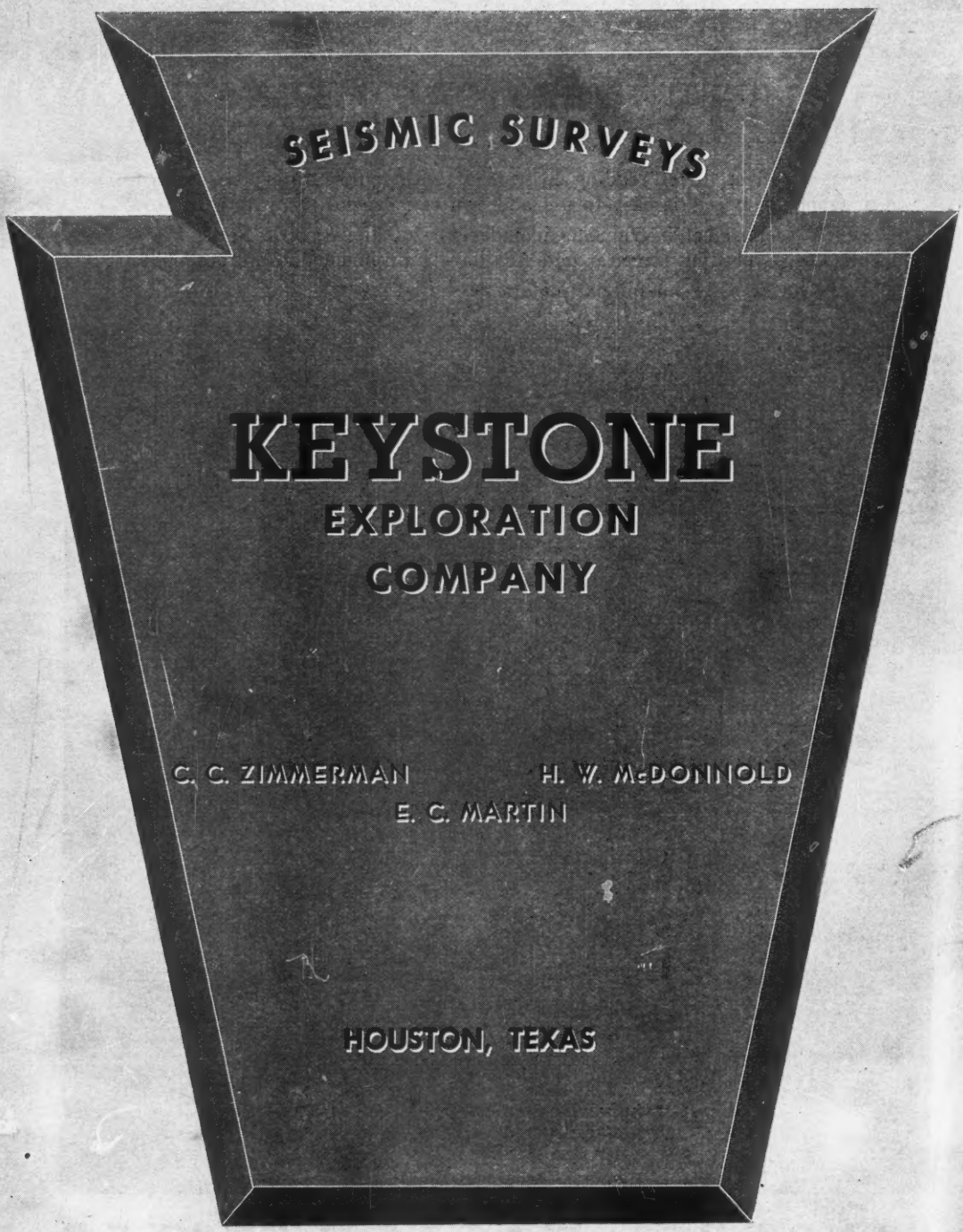
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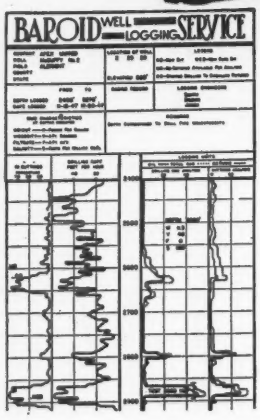

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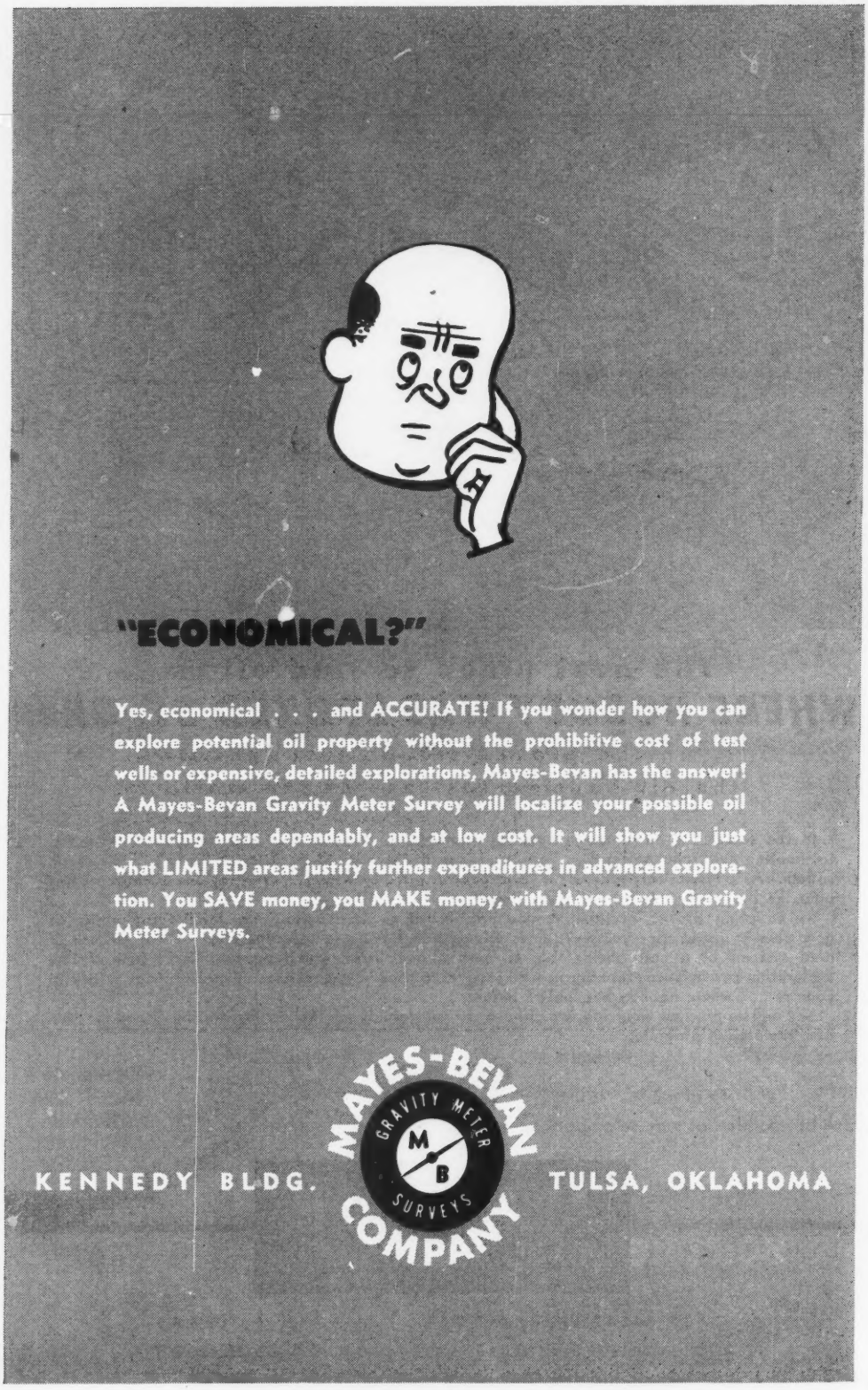
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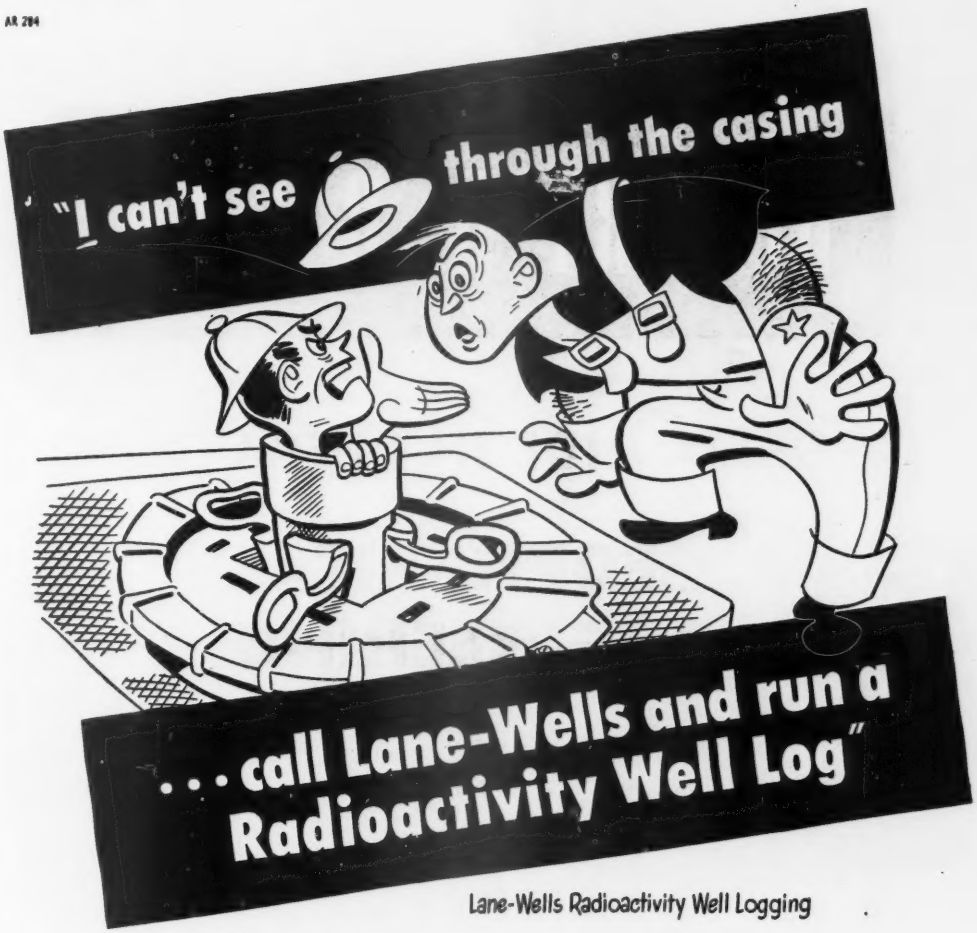

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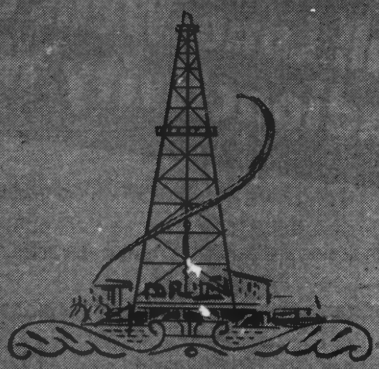

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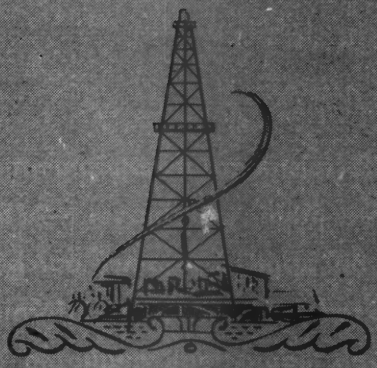

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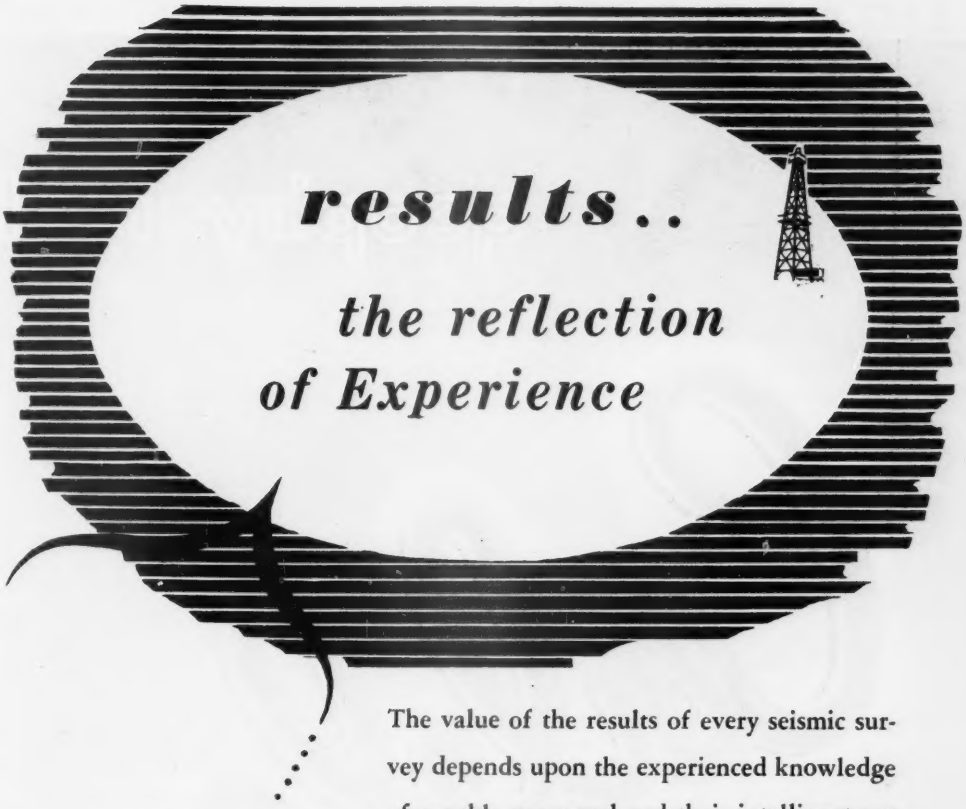

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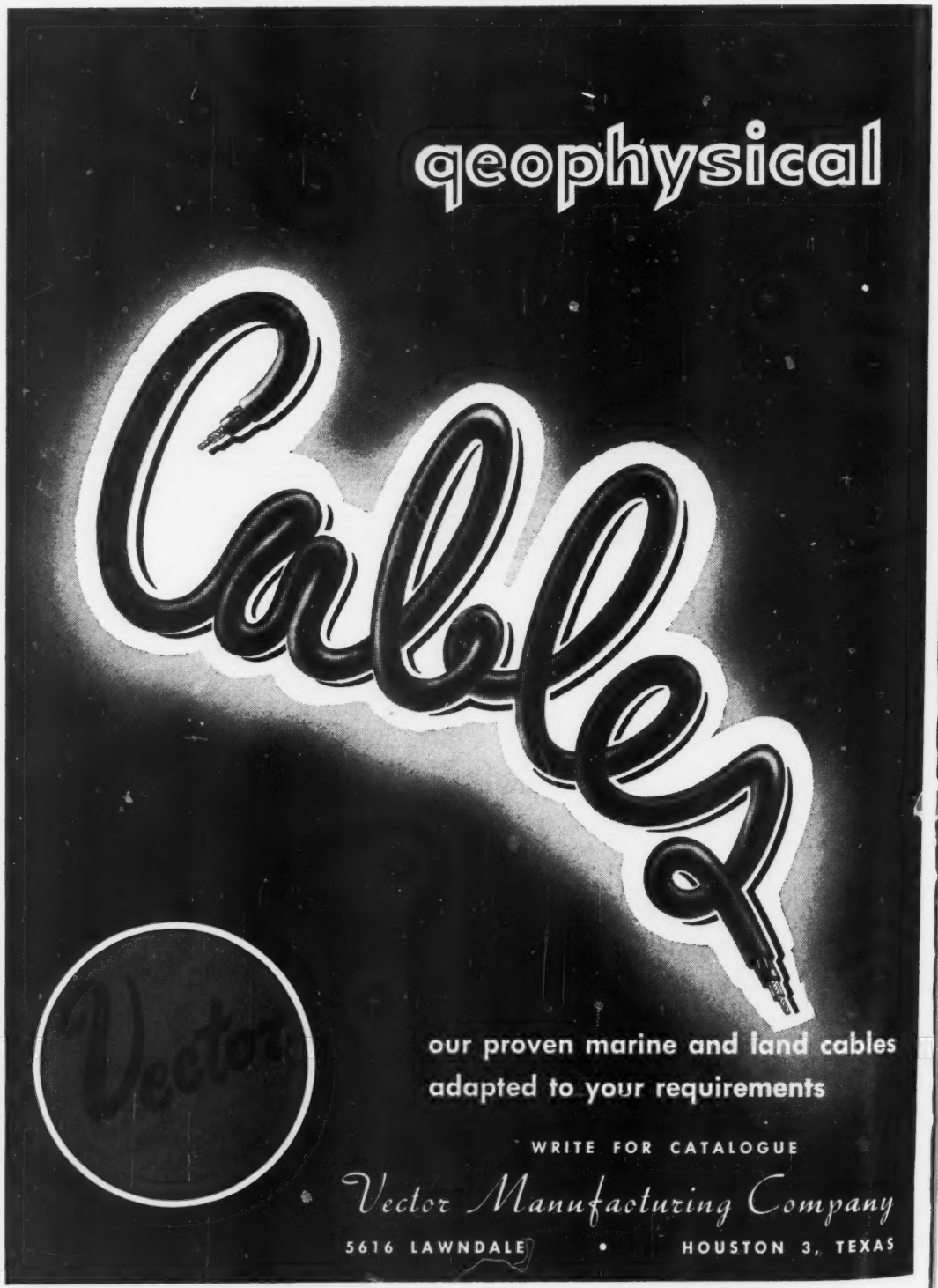
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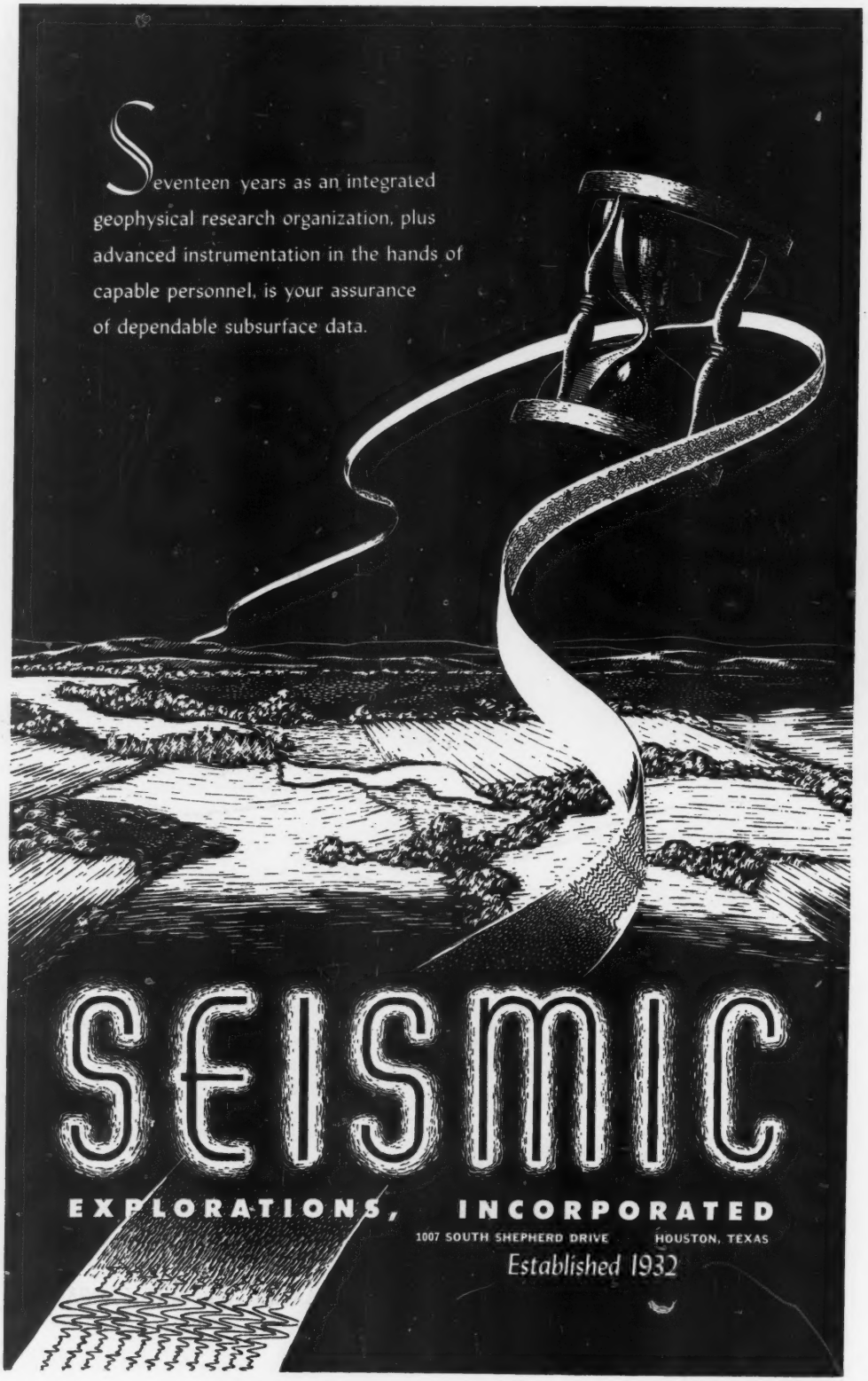
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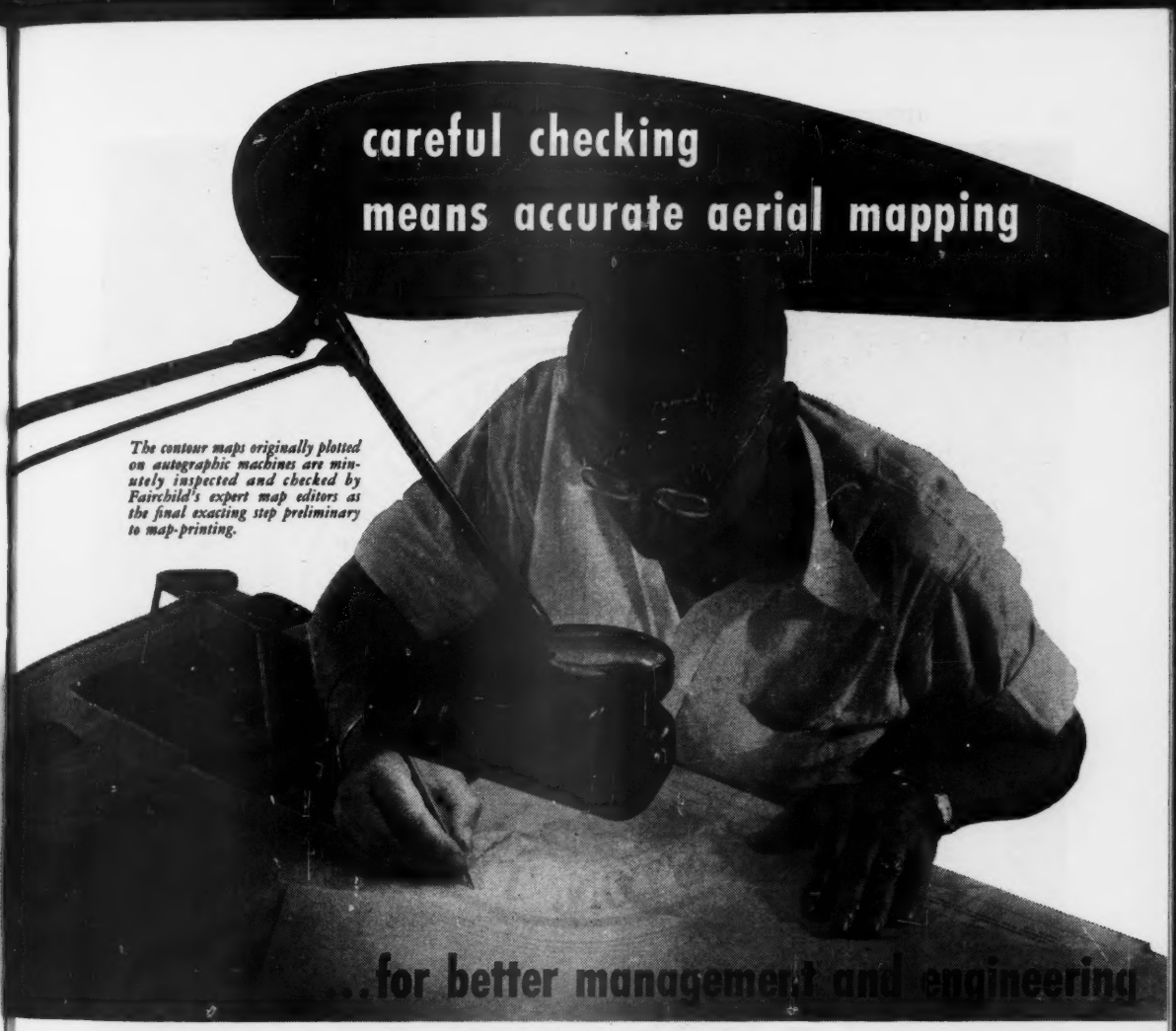
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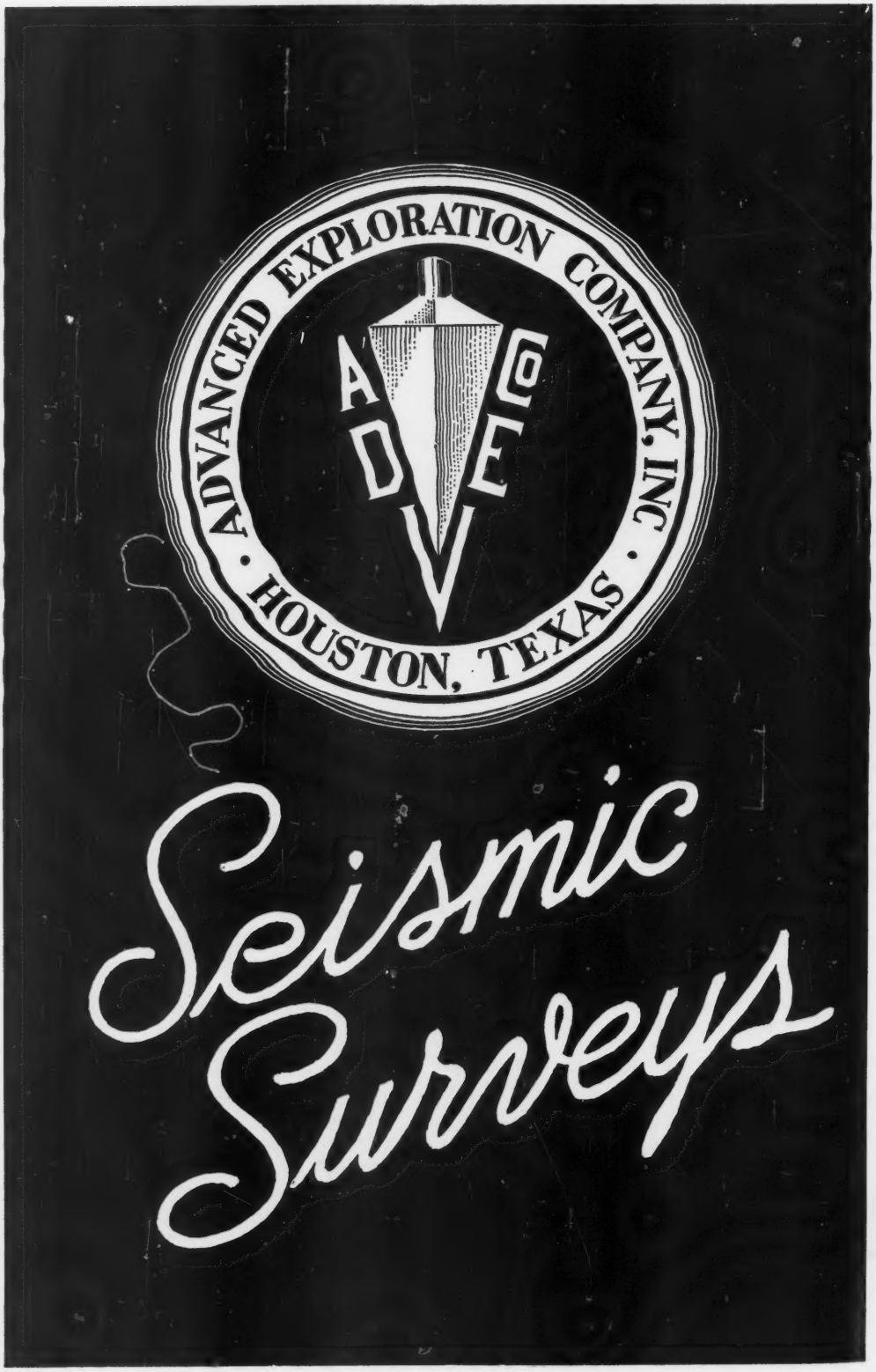
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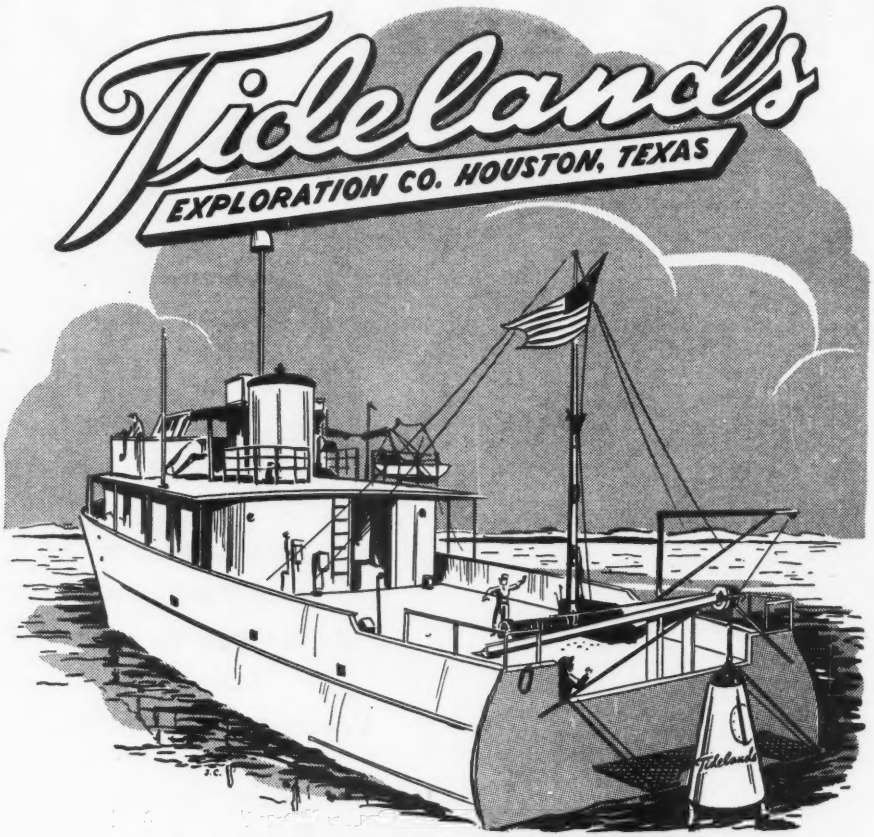

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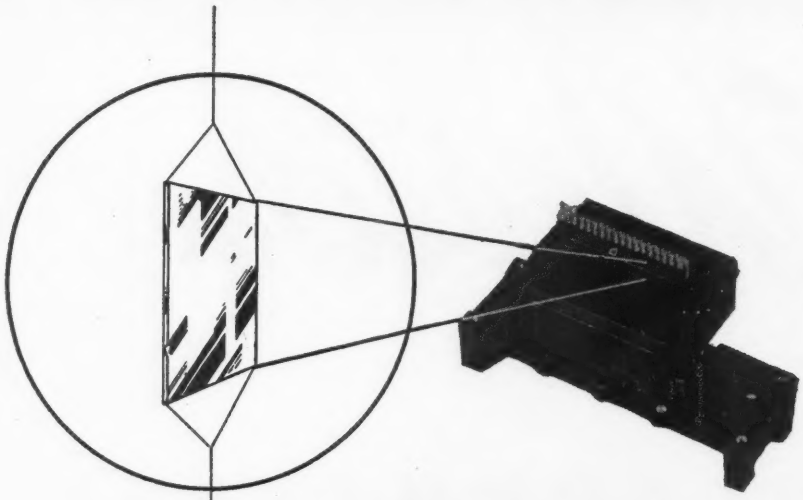

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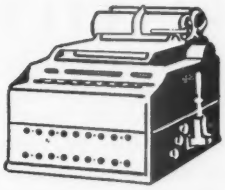

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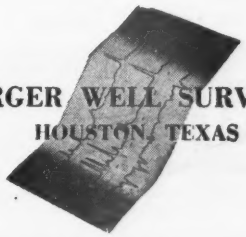

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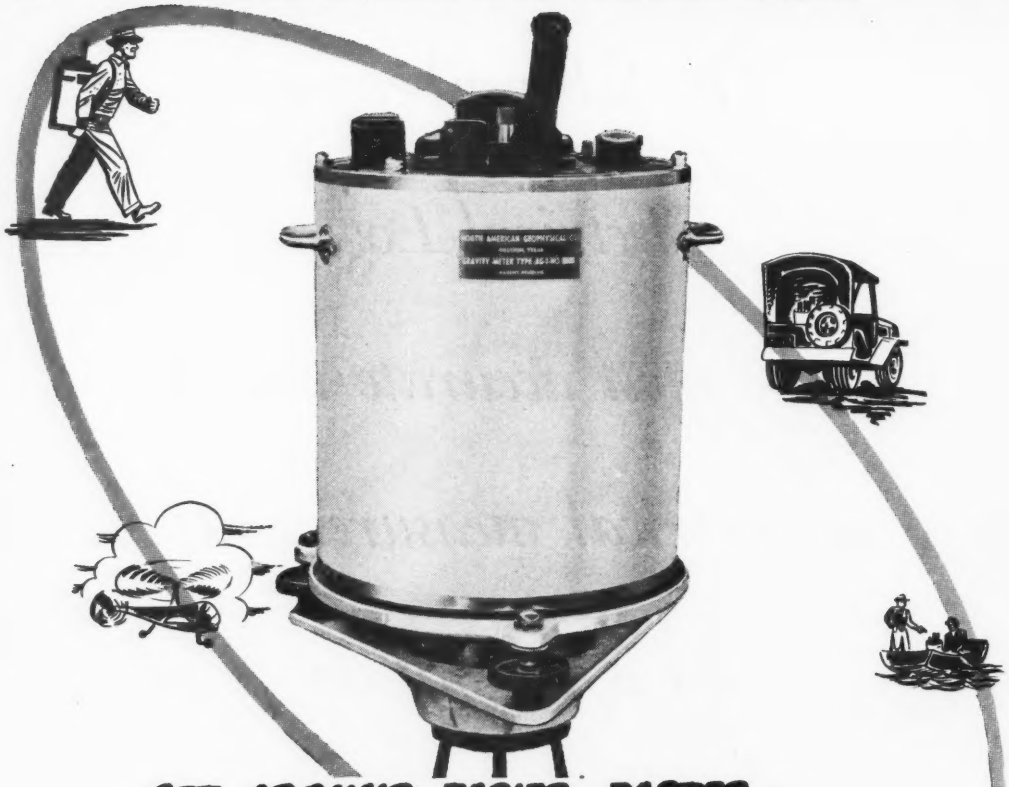

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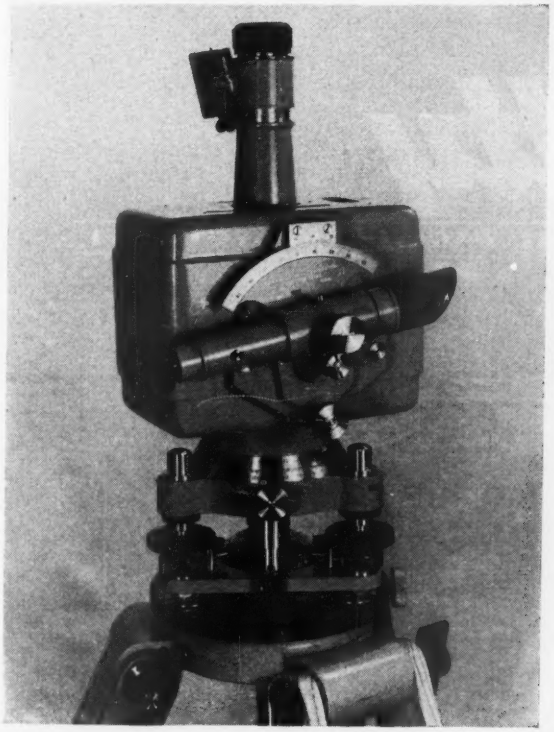

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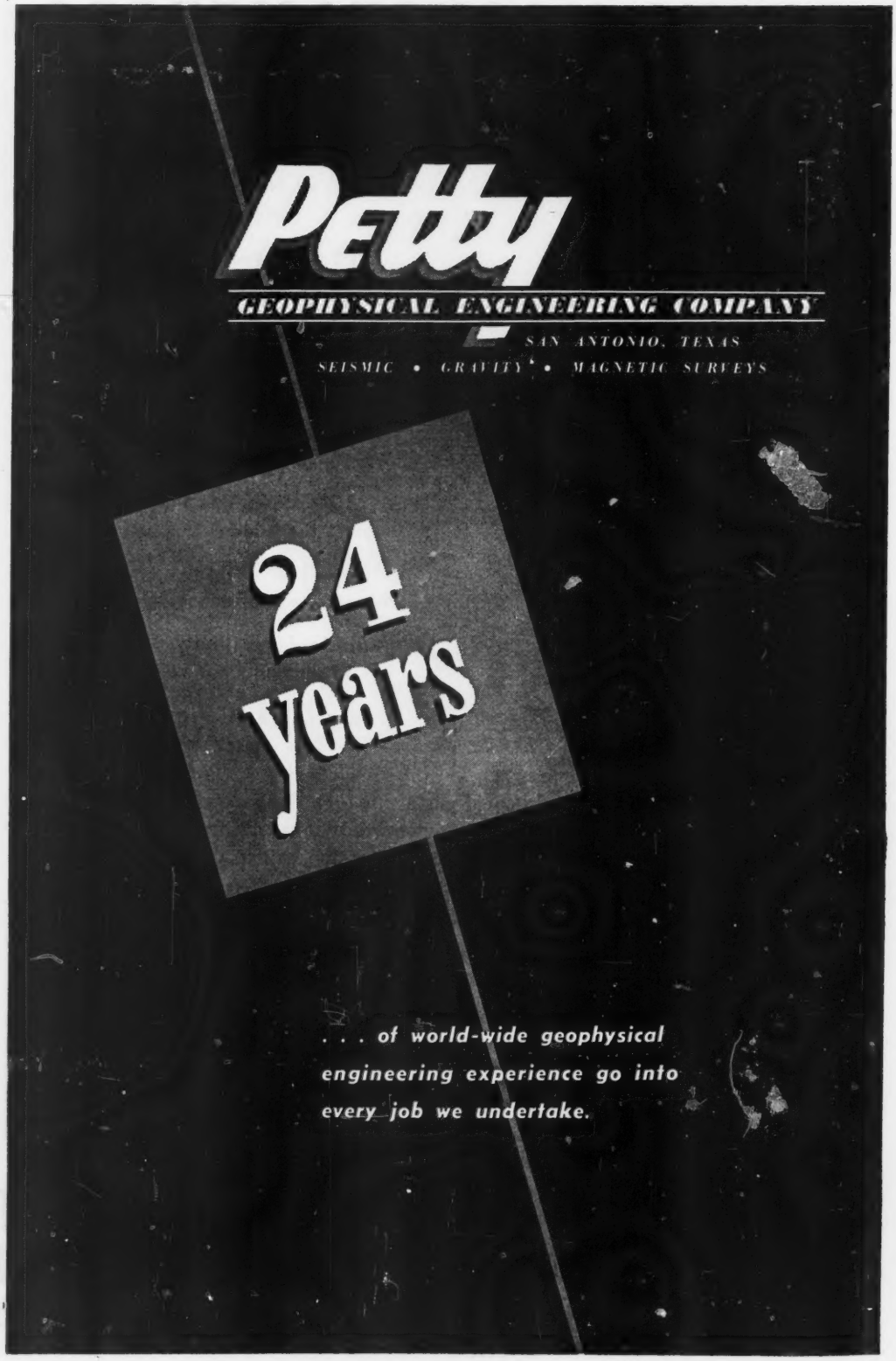
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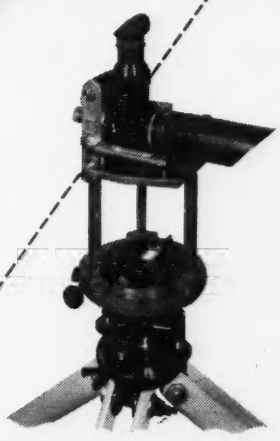

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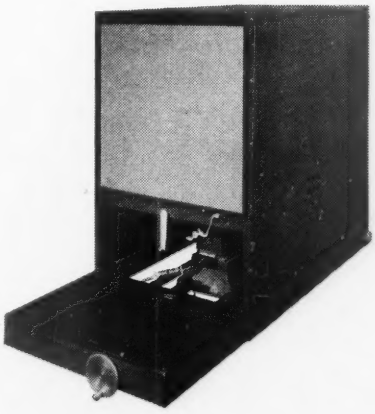

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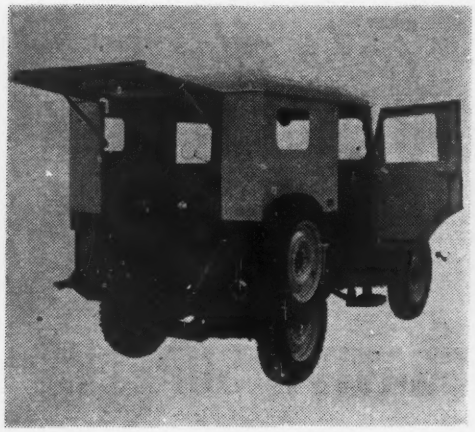

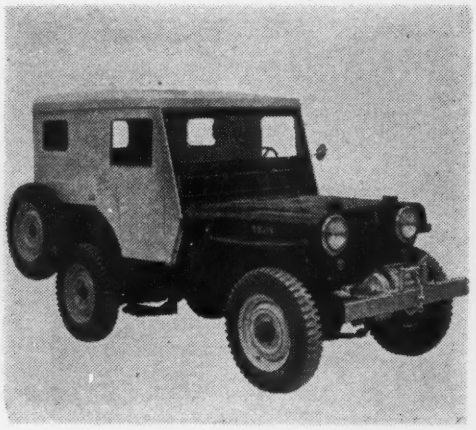

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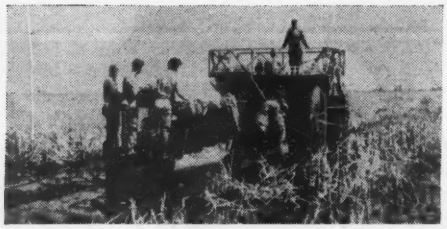

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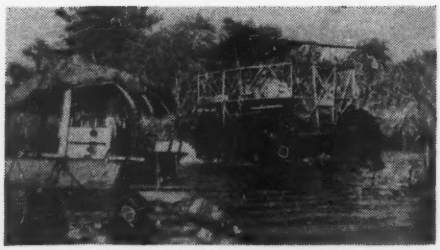

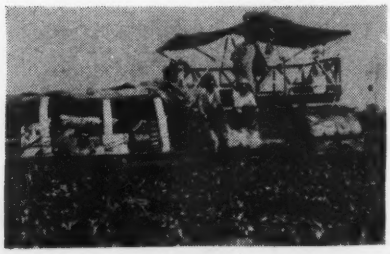

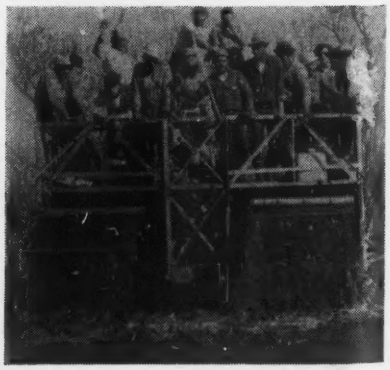

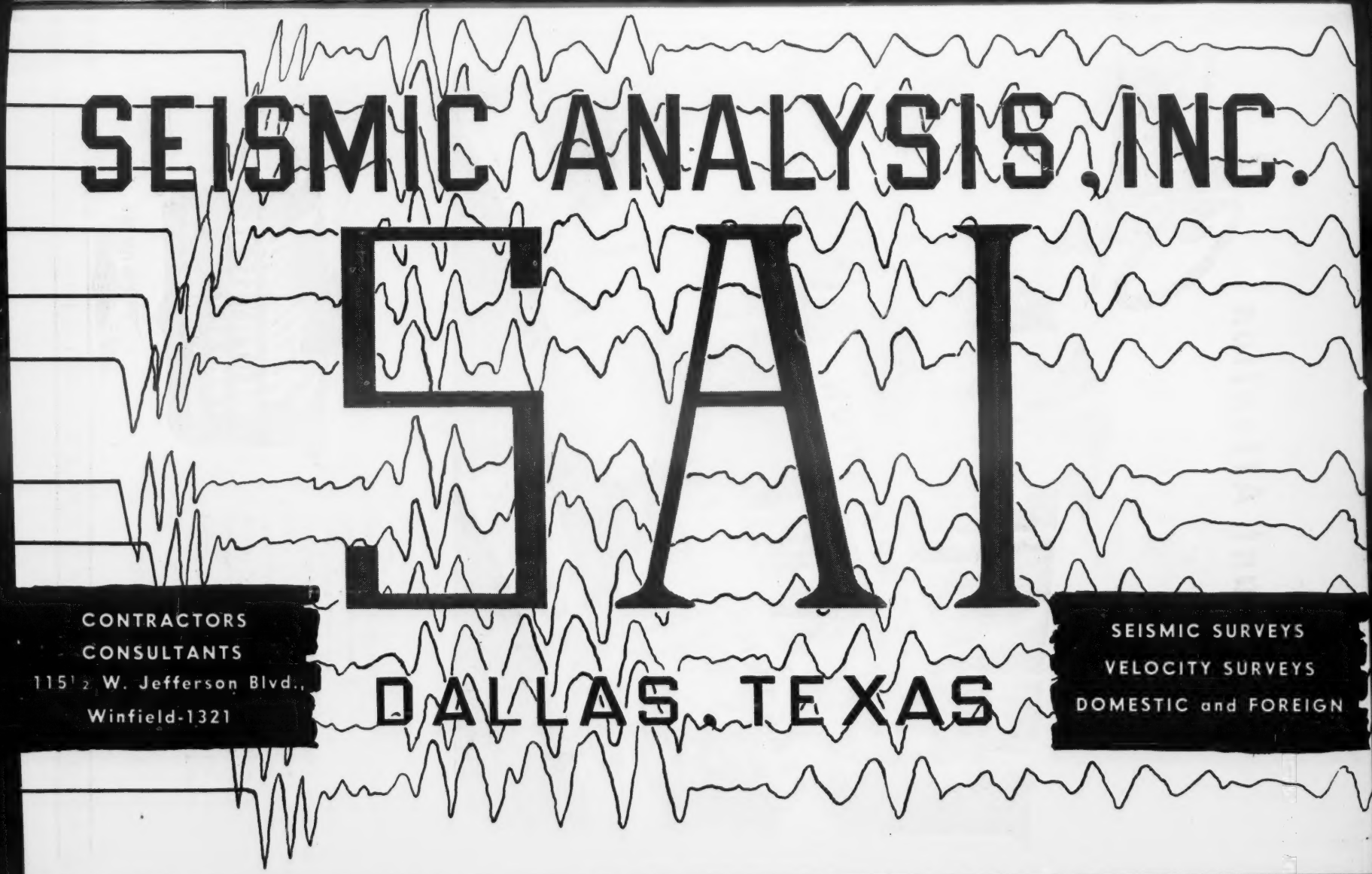
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DOMESTIC and FOREIGN

WHERE *Instant Attention* TO SPECIAL REQUESTS *Counts*

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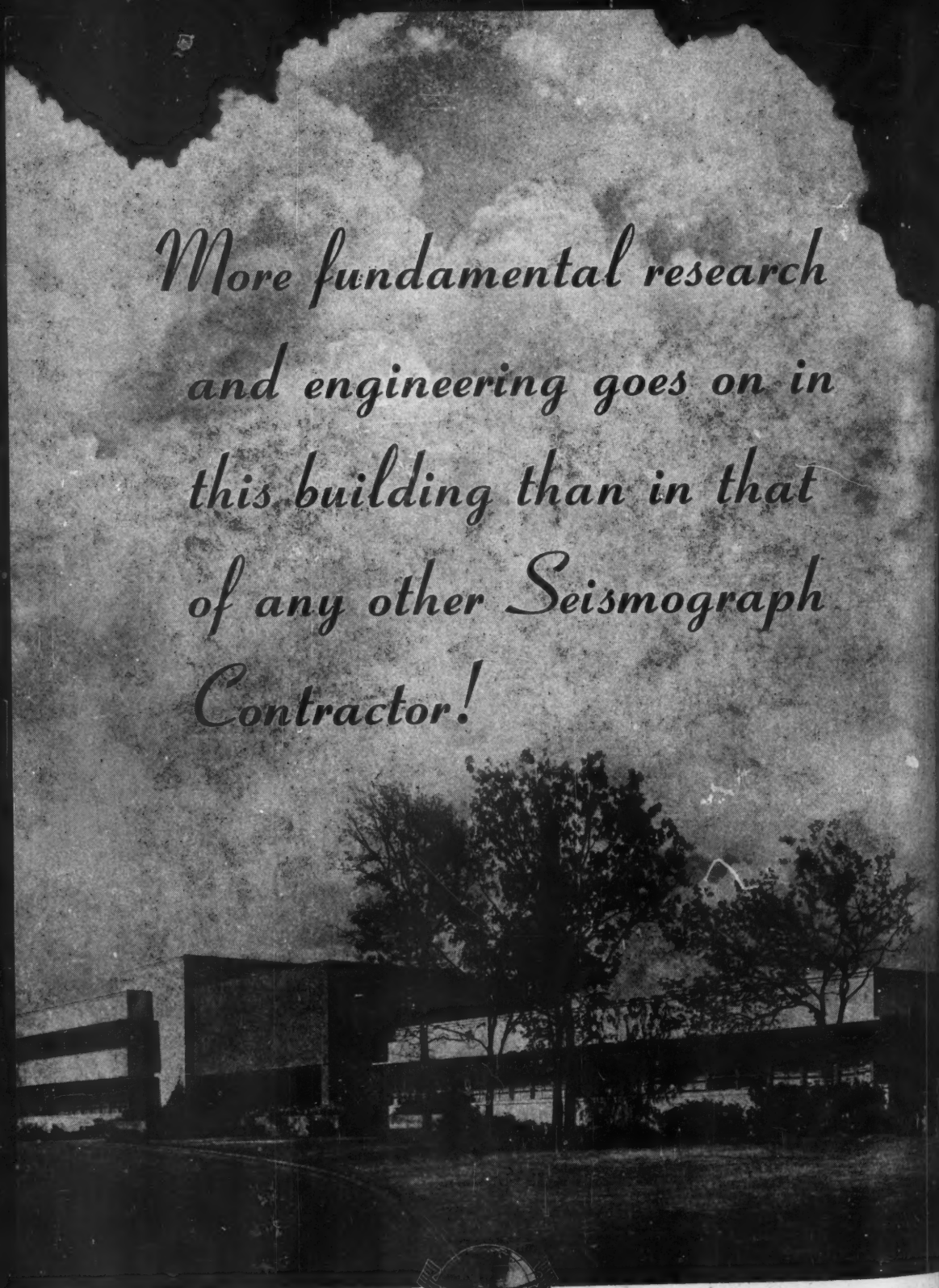

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